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# Rates of hillslope lowering in the Badlands of North Dakota

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*University of North Dakota*

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Rates of Hillslope Lowering in the Badlands  
of North Dakota

by  
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A Dissertation  
Submitted to the Faculty  
of the  
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in partial fulfillment of the requirements  
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This dissertation submitted by John R. Tinker, Jr.  
in partial fulfillment of the requirements for the  
Degree of Doctor of Philosophy from the University  
of North Dakota is hereby approved by the Faculty  
Advisory Committee under whom the work has been  
done.


  
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Degree Doctor of Philosophy

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## ABSTRACT

Measurements in a small drainage basin in the Little Missouri Badlands of western North Dakota indicate an average rate of hillslope lowering by slopewash of 0.41 inch per year on the west-facing hillslopes underlain by the Sentinel Butte Formation, 0.14 inch per year on the southwest-facing hillslopes underlain by the Tongue River Formation, and 0.11 inch per year on the northeast-facing hillslopes underlain by the Tongue River Formation. Soil creep occurs mainly on the Tongue River Formation and is mostly restricted to the northeast-facing hillslopes where the average rate of soil creep parallel to the hillslope surface is 0.23 inch per year in the upper 2.5 inches of surficial sediment. Erosion perpendicular to the face of seepage steps is 0.29 inch per year.

The Sentinel Butte Formation has a lower rate of infiltration and percolation, which results in a higher rate of surface runoff than on the Tongue River Formation. This in part causes the higher rates of lowering of the hillslope by slopewash on the Sentinel

Butte Formation than on the Tongue River Formation.

The lowering of the hillslopes by slopewash contributes 99.9 percent of the 43,000 cubic feet of sediment per year from the hillslopes in the study areas. Comparison of the hillslope sediment yield with the rates of valley-bottom deposition from June to July 1969 indicates that approximately 62 percent of the hillslope sediment left the drainage basin.

## INTRODUCTION

### General Statement

In the past, nonquantitative and quantitative theoretical approaches have been used to explain the change in geomorphologic features with time. A theoretical approach involves the acceptance of a basic assumption or model from which is derived a set of conclusions. Recently, however, empirical approaches have been used directly to monitor changes in a landscape feature with time. An empirical approach involves either a laboratory or a field technique for observing or measuring a geomorphologic process.

The importance of determining the present rates of geomorphologic processes is to provide a standard for comparison of past and future rates of these processes. In the United States, little data exists from the direct observation of the present rates of hillslope lowering. In western North Dakota, no data is available.

### Purpose

The study reported here used an empirical approach consisting of the direct monitoring of hillslope lowering by slopewash, soil creep, and seepage-step retreat on the Tongue River and Sentinel Butte Formations in the



Little Missouri Badlands of western North Dakota. The study site is located in the South Unit of the Theodore Roosevelt National Park in the basin of Buffalo Creek, lat  $46^{\circ} 58'$  N., long  $103^{\circ} 28'$  W., in the  $N\frac{1}{2}$ , sec. 7, T. 140 N., R. 101 W. (Figure 1). Most of the hillslope erosion sites were established during July of 1967 and were monitored April 9, 1968, August 4, 1968, November 23, 1968, April 15, 1969, June 18, 1969, and July 29, 1969. At these times, sediment loss and surface characteristics of the hillslopes were recorded. Monitoring devices to measure valley-bottom deposition and erosion were established June 18, 1969 and were monitored July 29, 1969.

#### Previous Work

Rates of hillslope lowering by slopewash and soil creep in semiarid areas as determined by various workers are summarized in table 1 and 2. Schumm (1964) concluded that although lowering of the hillslope by slopewash must have occurred at his site, any progressive exposure of the stakes during the 4 years of measurement was masked by seasonal changes. He later observed that the average rate of rock creep on Mancos Shale hillslopes in western Colorado was directly proportional to the sine of the slope angle (Schumm, 1967). Rock creep was measured by the movement of rock fragments from fixed points. Rates of hillslope

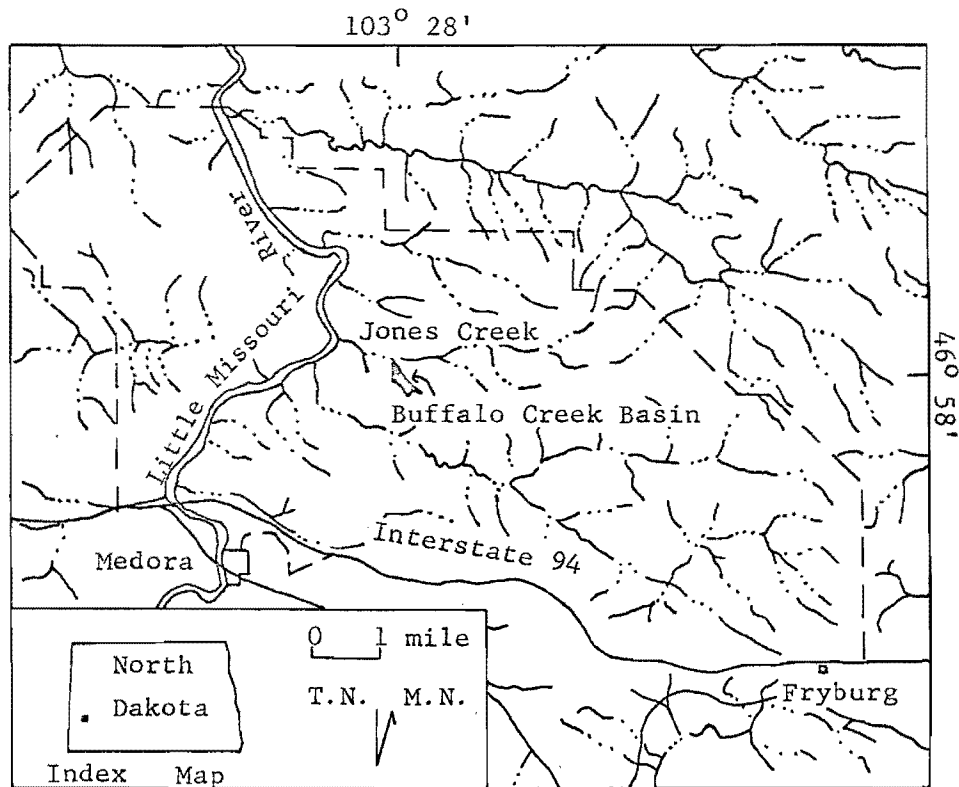


Figure 1.--Study area in Buffalo Creek basin, a tributary of Jones Creek.

Table 1.--Rates of hillslope lowering by slopewash for selected sites in the semiarid United States.

AUTHOR	LOCATION	TECHNIQUE	EROSION inches/year	YEARS OF MEASUREMENT
Emmett (1965)	Mittenrock, New Mexico	25 nails and washers	0.18	1.0
	Hudson, Wyoming	56 nails and washers	0.28	1.0
	Forsaken Gully, Montana	27 nails and washers	0.64	1.0
	"	18 nails and washers	0.40	1.0
	New Mexico	57 nails and washers	0.18	5.0
	"	65 nails and washers	0.29	3.0
	"	61 nails and washers	0.10	5.0
Schumm (1956b)	Badlands South Dakota	wooden stakes	0.08 to 1.50	2.1
(1964)	Montrose and Badger Wash, Colorado	metal stakes	0.00	4.0

Table 1.--Continued.

AUTHOR	LOCATION	TECHNIQUE	EROSION inches/year	YEARS OF MEASUREMENT
Hadley and Schumm (1964)	Sioux County, Nebraska	iron rods	0.6 to 1.8	1.0
	"	"	0.3 to 1.8	1.3
Leopold and others (1966)	Arroyo de los Frijoles, Santa Fe, New Mexico	61 pins	0.10	5.0
		57 pins	0.17	5.0
		65 pins	0.29	5.0
		20 pins	0.23	5.0
		15 pins	0.30	5.0
		19 pins	0.08	6.0

Table 2.--Rates of soil creep parallel to the hillslope  
for selected sites in the semiarid United States.

AUTHOR	LOCATION	TECHNIQUE	MOVEMENT inches/year	YEARS OF MEASUREMENT
Emmett (1965)	Mittenrock, New Mexico	Surveying from a known benchmark	0.00	1.0
	Santa Fe New Mexico	?	0.14	1.0
	New Mexico	Surveying from a known benchmark	0.20	3.0
	Forsaken Gully, Montana	Taping distances from a known benchmark	0.43	1.0
Leopold and others (1966)	Arroyo de los Frijoles	surveying from a known benchmark	0.21	5.0
	Santa Fe, New Mexico		0.20	3.0

lowering by slopewash and soil creep in humid areas have been reported by Schumm (1956a), Emmett (1965), and Kirkby (1967). Hadley and Rolfe (1955) measured 4.2 inches per year of retreat of seepage steps in eastern Wyoming and western South Dakota and Nebraska. The techniques and importance of all such studies have been evaluated by Leopold (1962), Miller and Leopold (1963), Emmett (1965), Leopold and Emmett (1965), and Hadley (1965).

Hagmaier (1967) presented the linear, areal, and relief aspects of Buffalo Creek basin. He calculated a stream frequency of 540 streams per square mile, a mean basin gradient of 8 percent, and determined that the basin is in the equilibrium stage of the erosion cycle as defined by Strahler (1952). Hamilton (1967) has presented information on arroyo development and retreat and has recognized a stratigraphic sequence of recent alluvial fills for the Little Missouri Badlands. Bell (1968) has discussed the importance of the hillslope process of piping in the Little Missouri Badlands.

### Physical Environment

#### Climate

The climate of the study area is semiarid. The closest

meteorological station is at Medora, North Dakota, approximately 10 miles south of the study area. The mean annual rainfall from 1952 to 1968 was 14.97 inches, most of which occurred between April and September (Table 3). The mean annual temperature for this same interval was 42.9° F. The lowest mean monthly temperature occurs in January and the highest mean monthly temperature occurs in July. The total precipitation at Medora during the 2 years of field measurements was 35.52 inches (Figure 2).

#### Stratigraphy

Buffalo Creek basin is underlain by the Paleocene Tongue River and Sentinel Butte Formations of the Fort Union Group (Figures 3 and 4). At the top of the Tongue River Formation is the scoria of the HT Butte bed. The hillslope erosion sites are on the upper 80 feet of the Tongue River Formation and the lower 110 feet of the Sentinel Butte Formation.

Several tens of feet of valley fill occur in the bottom of Buffalo Creek basin.

#### Vegetation

Short to medium grasses such as blue grama, needle and thread, and western wheat grass occur on the southwest-

Table 3.--Climatic data from 1952 to 1968 for Medora,  
North Dakota. (U. S. Weather Bureau, 1952 to 1968).

	Jan.	Feb.	Mar.	Apr.	May	June	July
Mean Temp. (Degree F.)	13.5	19.6	28.5	41.9	54.3	63.7	70.3
Mean Precip. (Inches)	.72	.41	.63	1.40	2.02	3.65	2.11
	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	
Mean Temp. (Degree F.)	69.0	57.1	46.6	30.1	19.4	42.9	
Mean Precip. (Inches)	1.69	1.16	.54	.47	.27	14.97	



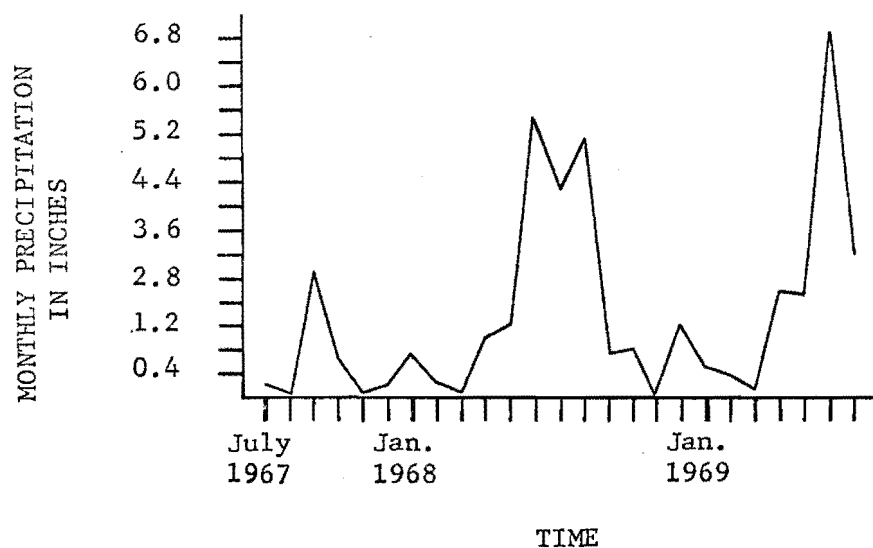


Figure 2.--Average monthly precipitation from July 15, 1967 to July 29, 1969 for Medora, North Dakota (U. S. Weather Bureau, 1967-1969).

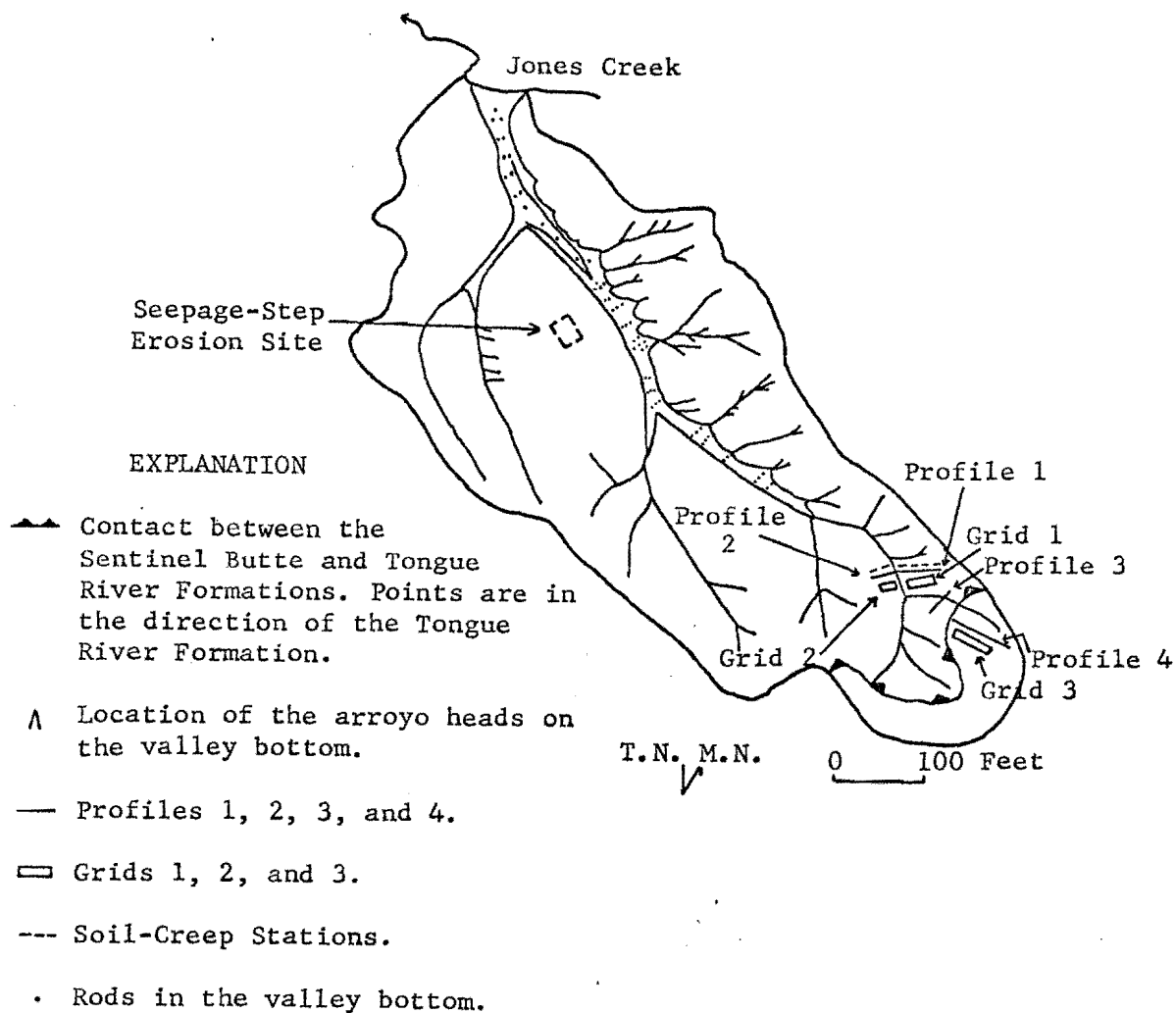


Figure 3.--Location of the Tongue River and Sentinel Butte Formations, profiles, grids, the seepage-step erosion site, the rods used to measure valley-bottom deposition, and topographic features in Buffalo Creek basin.



Figure 4.--Aerial view of the upper part of Buffalo Creek basin showing the contact between the light-colored Sentinel Butte Formation and the dark-colored Tongue River Formation. The color of the formations in this photograph is the result of differences in the amount of vegetation on the hillslopes and reverses the relationship when seen in the field or in color photographs.

facing hillslopes of the Tongue River Formation in Buffalo Creek basin (Figure 5). In contrast, thick sod, creeping and Rocky Mountain cedar, and various shrubs occur on the northeast-facing hillslopes of the same formation (Figure 6). The surface of the Sentinel Butte hillslopes is largely nonvegetated (Figure 7). Prairie grasses and some sagebrush grow on the valley fill in the bottom of the basin.



Figure 5.--Southwest-facing hillslope on the Tongue River Formation is shown in the foreground. Profile 1 and grid 1 are located here. Hillslopes on the Sentinel Butte Formation are shown in the background. The scale is given by the circled figure in the center of the photograph.



Figure 6.--Northeast-facing hillslope on the Tongue River Formation is shown in the central part of the photograph. Profile 2 and grid 2 are located here. The scale is given by the circled figure on this hillslope.





Figure 7.--West-facing hillslope on the Sentinel Butte Formation is shown in the upper half of this photograph. Profile 4 and grid 3 are located here. Hillslopes on the Tongue River Formation are shown in the lower half of the photograph. Note the wide gullies on these hillslopes. The scale is given by the circled figure in the center of the photograph just above the contact between the two formations.

## TECHNIQUES OF STUDY IN MEASURING HILLSLOPE LOWERING

### Field Techniques

#### Measurement of Slopewash

The lowering of the hillslope by slopewash was measured by observing the amount of exposure of (1) 4-foot and 2-foot iron rods without washers and (2) 6-inch and 3-inch rods with washers.

(1) Four-foot and 2-foot rods without washers were inserted normal to the surface and at 10-foot intervals from the crest to the bottom of the hillslopes (Figures 8 and 9). All rods were left exposed 4 to 8 inches and were labelled for later identification. Differences in exposed length of the rods at the time of each measurement revealed intervening erosion and deposition. However, expansion and contraction of the ground surface up and down the shaft of the rods masked the true rates of erosion and deposition. Therefore, the rates of hillslope lowering by slopewash obtained from the rods without washers are not representative of the true rates of hillslope lowering of the Tongue River and Sentinel Butte Formations.





Figure 9.--A 4-foot and 2-foot rod without washers measuring the lowering of the hillslope by slopewash shown in a west-facing hillslope on the Sentinel Formation. A pencil is shown for scale.



Figure 8.--A 4-foot and 2-foot rod without washers  
or measuring the lowering of the hillslope by slopewash  
are shown in a northeast-facing hillslope on the Tongue  
River Formation. A pencil is shown for scale.

(2) Six-inch and 3-inch rods were used following the method described by Emmett (1965). A 6-inch rod was slipped through a washer and driven into the slope, leaving 1-inch exposed (Figures 10 and 11). When erosion occurred, the washer slipped down the shaft of the rod a distance equal to the maximum amount of erosion. If any later aggradation occurred, the washer was buried. The net erosion is the difference between the maximum erosion and the amount of deposition. Three-inch rods and washers were also used in the same manner but most were loosened by ice crystal growth and cracking of the hillslope surface. None of the 6-inch rods on the Sentinel Butte Formation showed evidence of loosening. However, the data from several of the 6-inch rods on the Tongue River Formation were eliminated because of loosening of the rods. Rust-proof washers were used to prevent the possibility of having the washer stick to the shaft of the rod.

Because the 6-inch rods had washers, a correction of each individual measurement could be made to eliminate expansion and contraction of sediment up and down the shaft of the rods. This correction of the individual measurements was possible by observing several features which resulted from definite erosion. For example, when erosion occurred, especially on the Sentinel Butte





Figure 10.--A 6-inch rod and washer for measuring the lowering of the hillslope by slopewash are shown in a northeast-facing hillslope on the Tongue River Formation. A pencil is shown for scale.

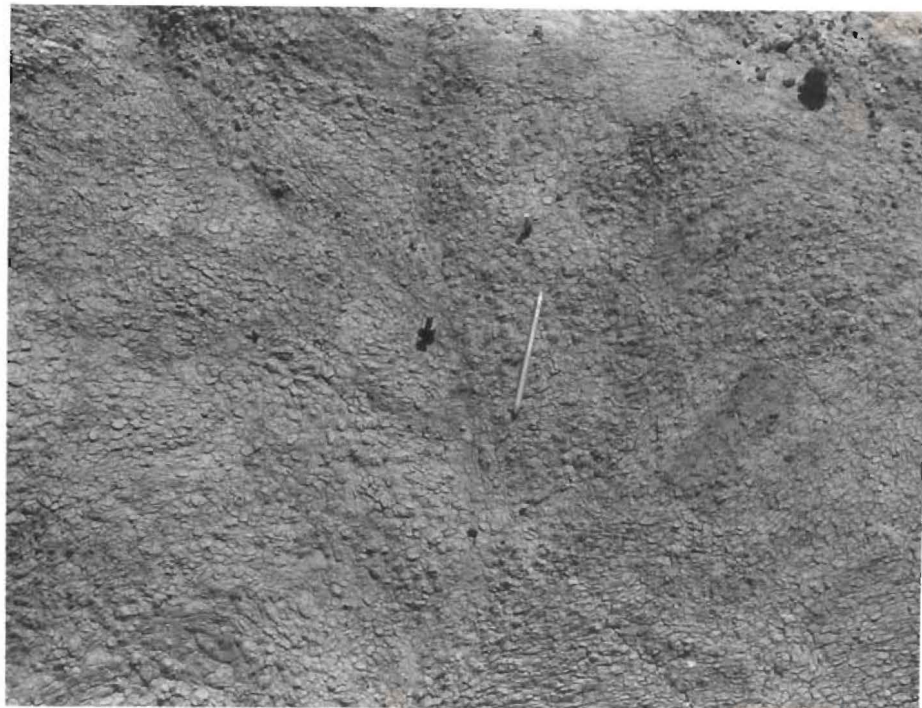


Figure 11.--A 6-inch and a 3-inch rod for measuring the lowering of the hillslope by slopewash are shown in a west-facing hillslope on the Sentinel Butte Formation. A pencil is shown for scale.

Formation, pedestals of sediment formed beneath the washers. These pedestals were direct proof that erosion had occurred. If a nail showed a decrease in exposure without sediment having been deposited on the washer, this was attributed to sediment expanding up the shaft of the rod. Only when the washer was buried was this recorded as deposition. Because of this ability to eliminate the effect of expansion and contraction of sediment up the shaft of the rods with washers, the rates of hillslope lowering by slopewash obtained from the rods with washers are taken as representative rates for the Tongue River and Sentinel Butte Formations.

#### Measurement of Soil Creep

The lowering of the hillslope by soil creep was measured by digging narrow pits to relatively unweathered bedrock or to a depth of 2.5 to 3 feet. Near the bottom of the pit, two 5-inch cotter pins were inserted in the side of the pit, one above the other normal to the slope and approximately 6 inches apart. A string was then passed through the head of each cotter pin, the two pins establishing a line normal to the surface of the hillslope. Along this line either glass or plastic beads or thin  $\frac{1}{2}$ -inch nails were placed. The string was

removed and the pit carefully filled. The site was re-excavated with great care at a later date. The cotter pins were relocated, the original line re-established assuming the deeply buried cotter pins had not moved because of their depth. The deviation of the beads or nails from the original line above the cotter pins indicated the degree of soil creep. This technique discerned sediment movement of as little as  $\frac{1}{16}$  inch. A total of 17 soil-creep stations were established during June 1968, and all were remeasured during June 1969.

#### Measurement of Seepage-Step Retreat

The lowering of the hillslope by seepage-step retreat was measured by changes in exposure of a line of rods with washers which were located transversely across a seepage step (Figure 12). Nineteen such sites were established in April 1968 on six different seepage steps. The sites were measured five times between April 1968 and July 1969.

#### Measurement of Sedimentation on the Valley Bottom

The sedimentation on the valley bottom of Buffalo Creek basin was measured with 54 4-foot rods with washers that were driven into the valley bottom in June 1969 (Figure 3). The rods were remeasured a month later.





Figure 12.--Two 4-foot rods and five 6-inch rods and washers (circled) placed transversely across a seepage step on the Tongue River Formation.



### Measurement of Hillslope Sediment Properties

The rate of infiltration of the hillslope surface was measured with a falling-head infiltrometer at six points on the Tongue River Formation and six points on the Sentinel Butte Formation. The rate of percolation of the hillslope sediment was measured by observing the drop in water level in auger holes that were 3 inches in diameter. Eight holes were augered on the Sentinel Butte Formation. Six of these sites were adjacent to the six locations used to determine the rate of infiltration, and the other two were situated elsewhere. Eleven holes were augered on the Tongue River Formation. Six adjacent to the six infiltration sites, and the remaining five were situated elsewhere.

### Laboratory Techniques

The particle-size distribution of 63 samples from the Tongue River and Sentinel Butte Formations was analyzed using a standard pipette method (Folk, 1964). The mineralogy of six selected samples from each formation was analyzed using x-ray techniques. Randomly oriented, oriented, glycolated, and heated samples were analyzed with an x-ray diffractometer. X-ray diffractometer charts of the randomly oriented samples were superposed on a calibrated chart and total mineral percentage determined

from peak heights. The chart used was corrected to a theoretical mass-absorption coefficient of 60.

## RATES OF HILLSLOPE LOWERING IN BUFFALO CREEK BASIN

### Study Areas

#### Tongue River Formation

Profile 1 and grid 1 are located on a southwest-facing hillslope on the Tongue River Formation (Figures 3 and 5). Profile 1 is composed of 32 4-foot and 2-foot rods without washers, and grid 1 is composed of 16 parallel rows of four to six pairs, each pair consisting of a 3-inch and a 6-inch rod with a washer. Profile 2 and grid 2 are located on a northeast-facing hillslope on the Tongue River Formation (Figures 3 and 6). Profile 2 consists of 30 4-foot and 2-foot rods without washers, and grid 2 consists of 14 rows of mostly six pairs, each pair consisting of a 3-inch and a 6-inch rod with a washer. Profile 3 crosses a small gully on the Tongue River Formation just up-valley from profile 1 and grid 1 (Figure 3). Profile 3 consists of 34 4-foot and 2-foot rods without washers.

The soil-creep stations are located on the Tongue River Formation immediately down-valley and parallel to profile 1 and 2 (Figure 3).

The seepage-step erosion site is located on the Tongue River Formation down-valley from the soil-creep stations (Figure 3 and 13).

#### Sentinel Butte Formation

Profile 4 and grid 3 are situated on a west-facing hillslope on the Sentinel Butte Formation (Figures 3 and 7). Profile 4 is composed of 48 4-foot and 2-foot rods without washers, and grid 3 is composed of 33 rows of from four to eight pairs, each pair consisting of a 3-inch and a 6-inch rod with washers.

#### Lowering by Slopewash

#### Observed Rates

#### Tongue River Formation

The 4-foot and 2-foot rods without washers of profile 1, 2, and 3 on the Tongue River Formation indicate that expansion and contraction of the ground surface up and down the shaft of the rods masks the true rates of erosion and deposition (Figures 14 and 15). Therefore, the rates of hillslope lowering obtained from the rods are not representative of the rates of hillslope lowering of the Tongue River and Sentinel Butte Formations. The probable cause of the expansion of sediment up the rods is (1) ice-crystal growth



Figure 13.--View of the seepage-step erosion site located on a northeast-facing hillslope of the Tongue River Formation. See figure 3 for the location of the seepage-step erosion site in Buffalo Creek basin.

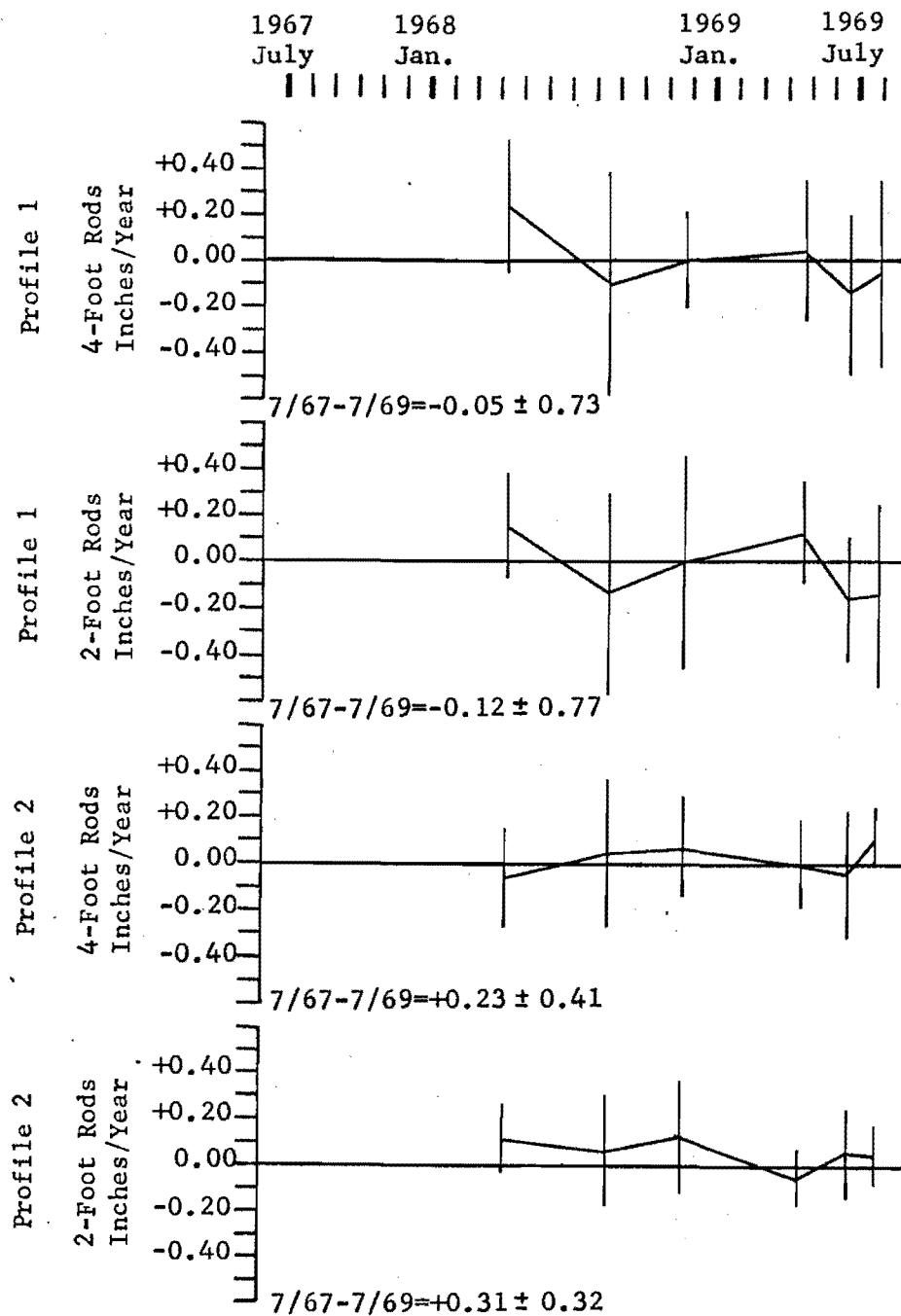


Figure 14.--Slopewash data for the 4-foot and 2-foot rods without washers at profile 1 and 2. The vertical lines represent the standard deviations. Positive numbers represent rate of deposition, negative numbers rate of erosion.

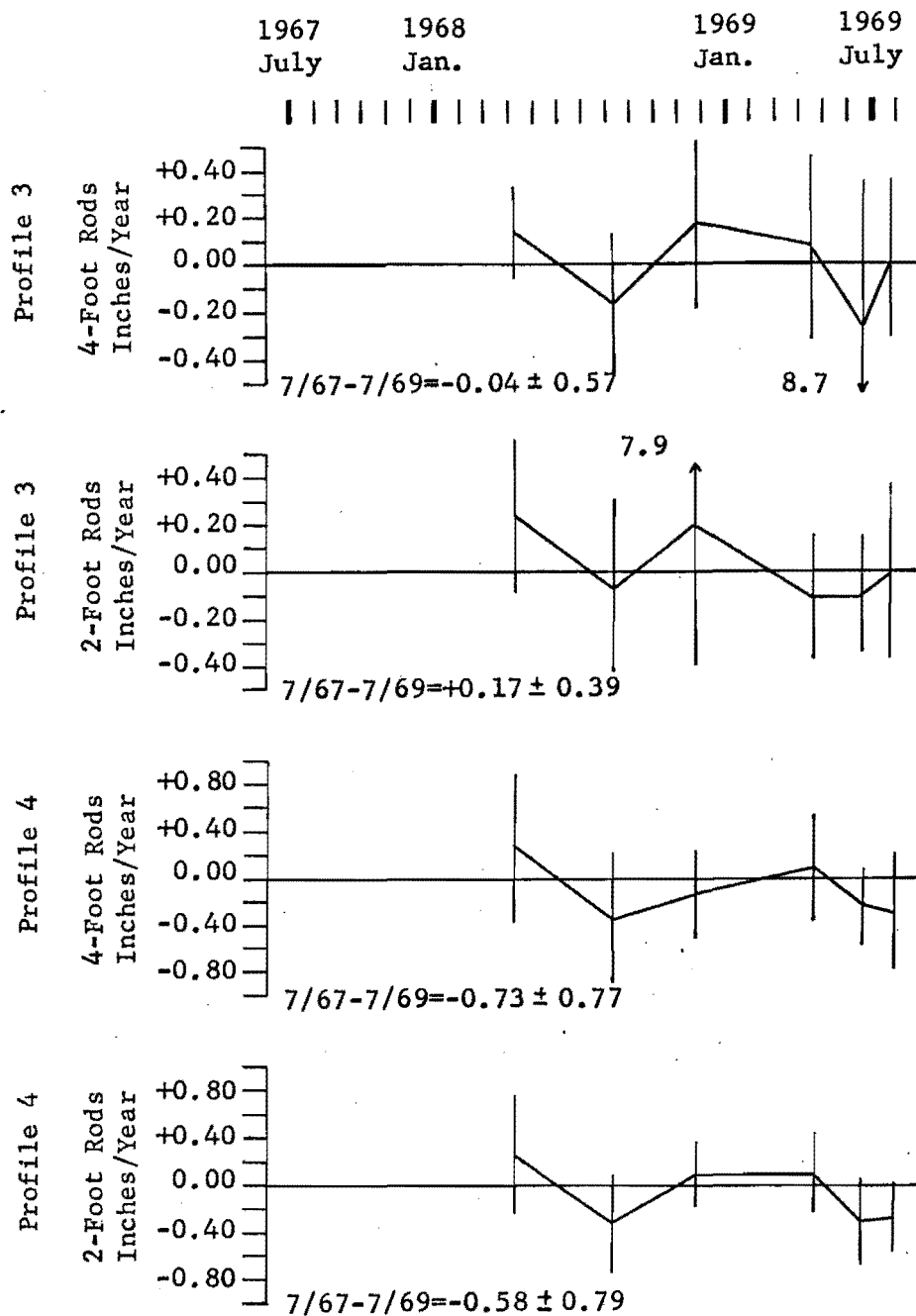


Figure 15.--Slopewash data for the 4-foot and 2-foot rods without washers at profile 3 and 4. The vertical lines represent the standard deviations. Positive numbers represent rate of deposition, negative numbers rate of erosion.

in the sediment near the surface in winter and early spring and (2) swelling of montmorillonite in the hillslope sediment during spring runoff or after a heavy storm. The probable cause of the contraction of sediment down the shaft of the rods is (1) compaction of the sediment by rainfall in the summer and fall and (2) the evaporation of sediment moisture from the hillslope sediment in the summer and fall. All of the basic data are in Appendix A.

The 6-inch rods with washers at grid 1 on the south-facing hillslope of the Tongue River Formation indicate a rate of hillslope lowering by slopewash of  $0.27 \pm 0.33$  inch for the two years of measurement (Figure 16). The 6-inch rods at grid 2 on the northeast-facing hillslope on the Tongue River Formation indicate a rate of hillslope lowering by slopewash of  $0.22 \pm 0.15$  inch for the same interval of time. All of the basic data are in Appendix B.

#### Sentinel Butte Formation

The 4-foot and 2-foot rods of profile 4 on the Sentinel Butte Formation showed the same expansion and contraction up and down the shaft of the rods as for the rods on the Tongue River Formation (Figure 15). All of the basic data are in Appendix A.

The 6-inch rods with washers on the west-facing hillslope of the Sentinel Butte Formation indicate a rate of hillslope lowering by slopewash of  $0.81 \pm 0.31$  inch for



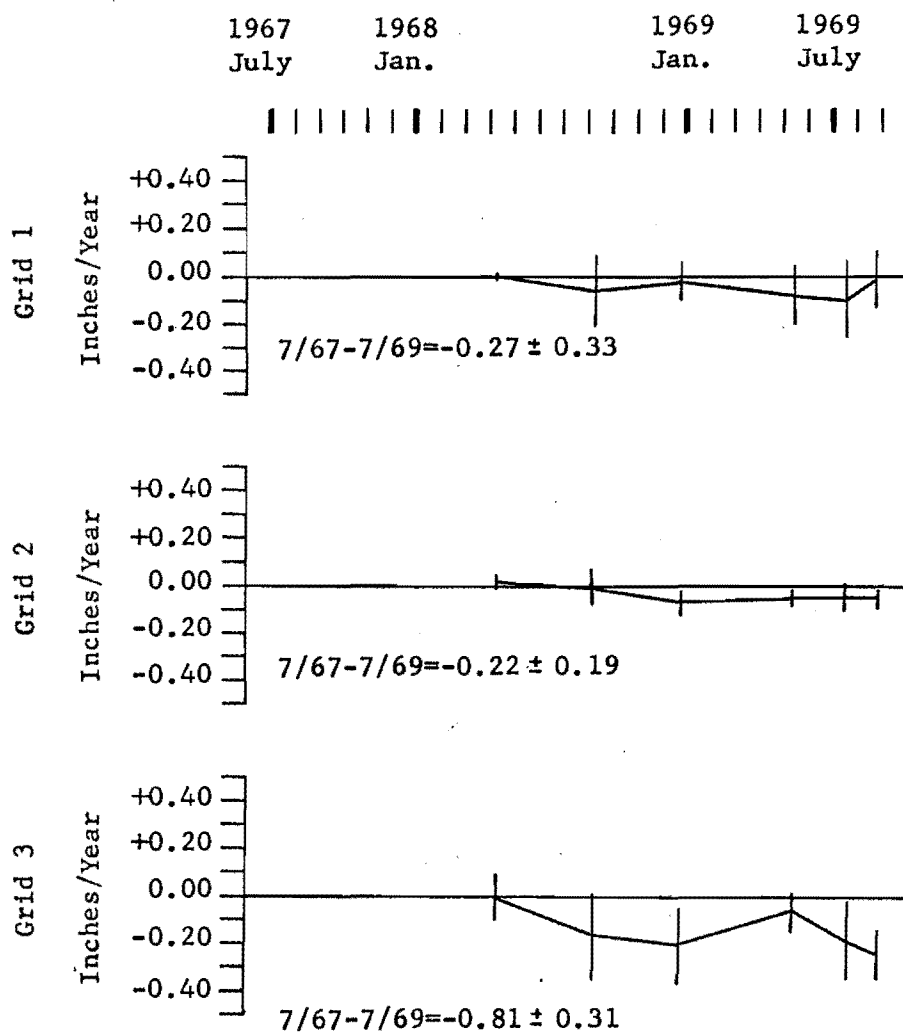


Figure 16.--Slopewash data for the 6-inch rods at grids 1, 2, and 3. The vertical lines represent the standard deviations. Positive numbers represent rate of deposition, negative numbers rate of erosion.

the two years of measurement (Figure 16). All of the basic data are in Appendix B.

#### Sediment Yield by Slopewash

The hillslope sediment yield in Buffalo Creek basin by slopewash from July 1967 to July 1969 was approximately 86,000 cubic feet of sediment (Table 4). This is an average yearly rate of 43,000 cubic feet of sediment. The rate of hillslope lowering obtained from grid 3 was used for all Sentinel Butte hillslopes in Buffalo Creek basin. All other major hillslopes in Buffalo Creek basin are northeast- or southwest-facing hillslopes.

#### Lowering by Soil Creep

##### Observed Rates

#### Tongue River Formation

The average downhill movement of sediment by soil creep on the northeast-facing hillslope of the Tongue River Formation is 0.23 inch per year between a depth of 0 to 2.5 inches (Figure 17). Soil creep on the southwest-facing hillslope of the Tongue River Formation is essentially zero. This results in a sediment yield of 29 cubic feet per year (see below) from the 3,300,000 square feet of Tongue River hillslopes. This is a hillslope lowering of 0.00009 feet per year.

Table 4.--The data for the calculation of hillslope sediment yield for the Tongue River and Sentinel Butte Formations in Buffalo Creek basin. The square footage of each hillslope was obtained from an aerial photograph with a scale of 1:4,800.

	S.W.-facing hillslope, Tongue River Formation Grid 1	N.E.-facing hillslope, Tongue River Formation Grid 2	Sentinel Butte hillslopes Grid 3
Square footage of hillslope surface	1,400,000	1,900,000	290,000
Rate of hillslope lowering by slopewash in inches 7/67 to 7/69	0.27	0.22	0.81
Cubic feet of sediment yield 7/67 to 7/69	32,000	34,000	20,000

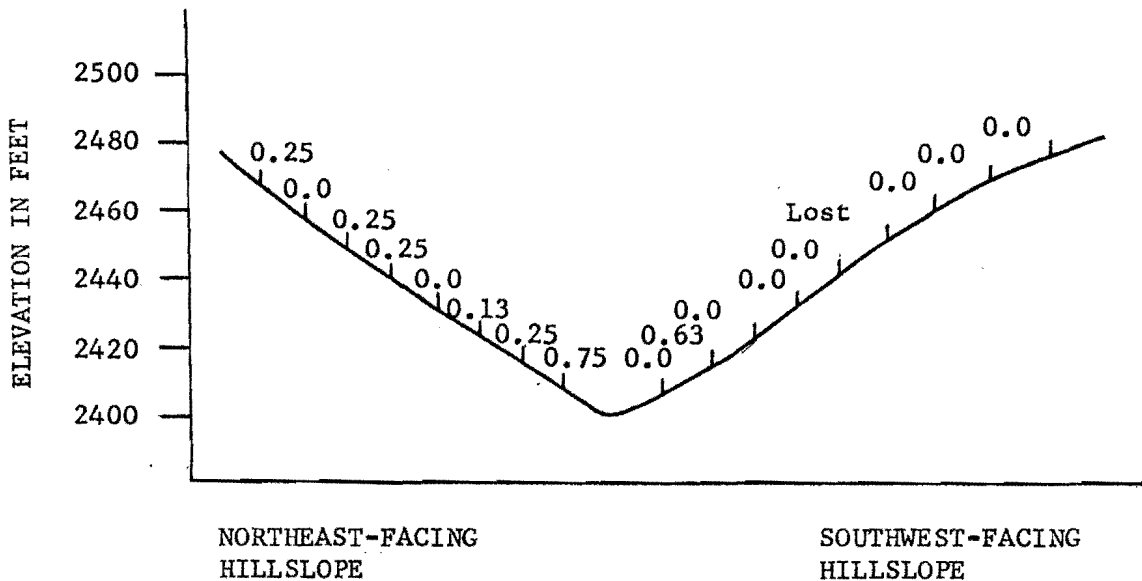


Figure 17.--Rate of soil creep in inches parallel to the hillslope surface of the Tongue River Formation in Buffalo Creek basin from July 1968 to July 1969.

### Sentinel Butte Formation

Soil creep was not measured on the Sentinel Butte Formation because hard nondiggable sediment is located at the surface of the Sentinel Butte hillslopes.

### Sediment Yield by Soil Creep

The sediment yield by soil creep from the northeast-facing hillslopes is 29 cubic feet per year. This figure is the product of the rate and depth of soil creep on the northeast-facing hillslopes and the total length of slope base of the northeast-facing hillslopes. The total length of slope base is approximately 7,500 feet and was obtained from an aerial photograph of a scale of 1:4,800. Although the scale of the aerial photograph did not allow the measurement of the length of slope base along the smaller gullies, the magnitude of this figure is probably correct. Therefore, the sediment yield by soil creep is only a fraction of a percent of the sediment yield by slopewash.

### Lowering by Seepage-Step Retreat

#### Observed Rates

### Tongue River Formation

Most of the seepage-steps on the Tongue River Formation

had a slightly different cross section than described by Hadley and Rolfe (1955) (Figure 18). Seventy-two percent had an additional surface between the seepage face and the base. This surface is named the basal slope (Figure 19).

The line of rods placed transversely across the seepage steps indicate that the seepage faces of the seepage steps are actively retreating upslope (Figure 19). Net erosion occurred both on the seepage face and at the lowest rod on the tread. Net deposition occurred at the upper rod on the tread, the rods on the basal slope, and at the lower rods in the base and in the debris slope. This net deposition of sediment is probably the result of erosion at the seepage face or the result of slopewash between and above the seepage steps. Alternating erosion and deposition was measured on the basal slope, base, and debris slope during the five periods of measurement. This probably indicates that these are surfaces of transportation of sediment from the seepage-face and tread to the debris slope and bottom parts of the hillslopes. Only on the debris slope was deposition occurring for most of the intervals of measurement. The upper rod on the tread was affected by both erosion and deposition on the uphill hillslope areas. The surface lowering by seepage-step retreat is negligible in comparison to soil creep and slopewash.

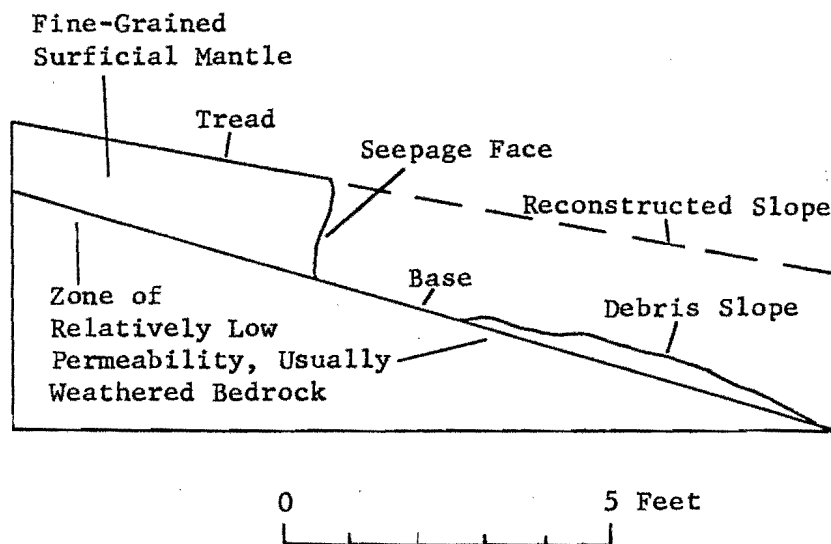


Figure 18.--Cross section presented by Hadley and Rolfe (1955) for seepage steps in the semiarid Great Plains.

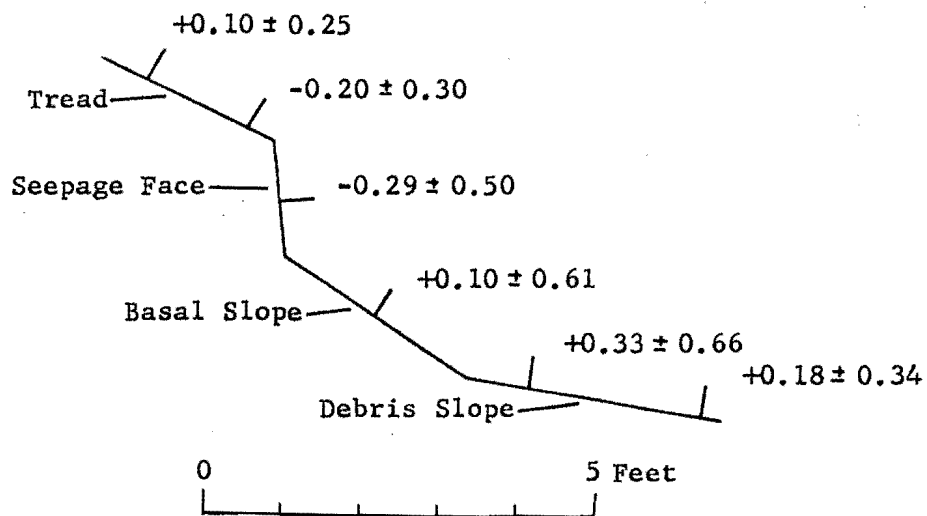


Figure 19.--Average cross section of the nineteen seepage steps at the seepage-step erosion site (Figure 3). Negative numbers indicate erosion in inches per year perpendicular to the slope, positive numbers deposition. All of the basic data is in Appendix C.



### Sediment Yield by Seepage-Step Retreat

The sediment yield from seepage-step retreat in Buffalo Creek basin is not known, because the area of the seepage faces for all seepage steps was not measured. Although seepage-step retreat is actively moving material down the hillslopes, the amount is most likely small in comparison to slopewash and soil creep.

### Lowering by Tunnelling

A hillslope process in Buffalo Creek basin that was not measured but which is important is tunnelling. Tunnelling is caused by subsurface erosion along desiccation cracks and joints in the hillslope sediment. Tunnels observed in the area of Buffalo Creek basin range from approximately 1 inch to 10 feet in diameter (Figures 20 and 21). One tunnel near Buffalo Creek basin was 100 feet long, 20 feet wide, and 25 feet high. Collapsing of a tunnel of this size deepens a hillslope gully by as much as 25 feet. The tunnels become smaller at both the lower and upper ends and narrow into smaller openings and cracks. The larger tunnels are widened and become higher when joint blocks fall from the roof and sides. Sediment is transported out the tunnel along cracks intersecting a free face. The longitudinal orientation of tunnels varies from the vertical



Figure 21.--A medium-sized tunnel on the Sentinel Butte Formation. The figure is just to the right of the tunnel.

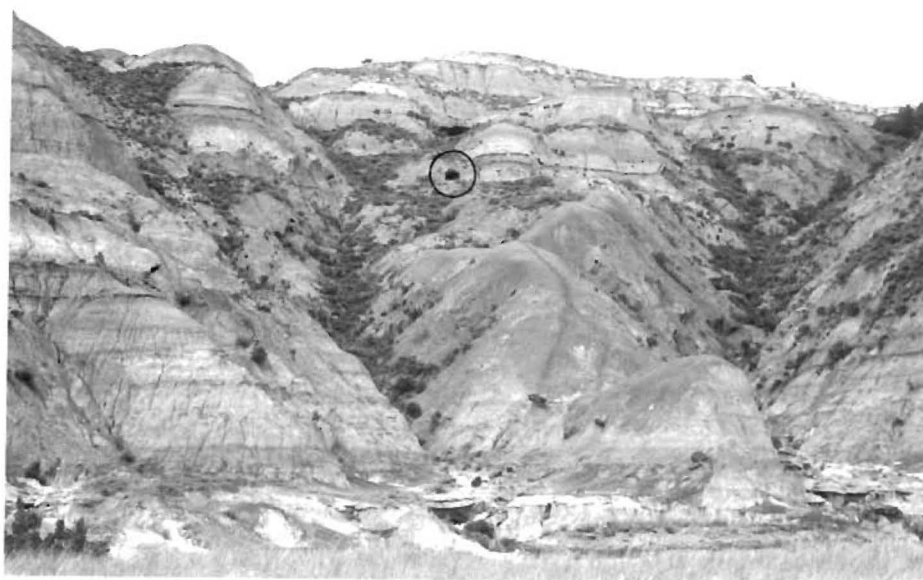


Figure 20.--Two large gullies underlain by a tunnel system are shown on the Sentinel Butte Formation. The entrance to a 5-foot diameter tunnel is circled in the center of the photograph.

to horizontal.

The rate of hillslope lowering and sediment yield by tunnelling is of definite importance and should not be neglected as a hillslope process.

#### Lowering by Dry Sliding

The flaking, crumbling, and rapid sliding of dry sediment from the hillslope surface during dry periods was observed as an active hillslope process on some steep hillslopes of the Sentinel Butte Formation. The importance of this hillslope process is not known; however, the rate of hillslope lowering and sediment yield is probably minor in comparison to slopewash and soil creep.

#### Lowering by Other Types of Mass Movement

Almost every conceivable type of mass movement occurs in Buffalo Creek basin. Various types of flows and slides move sediment from the hillslopes to the valley bottom. Even though this movement is sometimes quite spectacular, the overall rate of hillslope lowering and sediment yield is probably small in comparison to slopewash.

## CAUSES OF THE DIFFERENT RATES OF HILLSLOPE LOWERING IN BUFFALO CREEK BASIN

### Introduction

The data obtained during the two years of measurement indicates that no single factor controls hillslope lowering in Buffalo Creek basin. The rate of hillslope lowering is affected by a combination of factors; topography, sediment properties, permeability within the hillslope sediment, vegetation, and precipitation are just some of the factors that influence the rate of hillslope lowering.

### Topography

The topographic characteristics that affect the rate of hillslope lowering are (1) position on the slope, (2) angle of the slope, (3) shape of the slope.

(1) To determine if a greater amount of sediment was eroded from a specific location on the hillslope, the average rate of hillslope lowering by slopewash for each row of rods of grid 1, 2, and 3 was graphed against the distance of each row from the crest of the hillslope. The coefficient of correlation, Pearson's  $r$ , was calculated, and the results indicate no correlation between erosion at a specific point and distance from the crest of the hillslope. This indicates

that the hillslopes are retreating in a direction perpendicular to the hillslope surface.

(2) The higher angle of slope of the southwest-facing hillslope than the northeast-facing hillslope (Table 5) partly explains the higher rate of hillslope lowering by slopewash on the southwest-facing hillslope. However, the angle of slope of the southwest-facing hillslope of the Tongue River Formation is similar to that of the west-facing hillslope of the Sentinel Butte Formation. This similarity can not explain the difference between the rates of hillslope lowering by slopewash for these hillslopes. Also, the calculation of the coefficient of correlation indicated no correlation between the lowering of the hillslope by slopewash at each rod and the slope at each rod for grid 1, 2, and 3.

(3) Hillslope erosion on the Tongue River Formation is predominantly the result of unconcentrated flow (Table 5). Hillslope erosion on the Sentinel Butte Formation is mainly the result of concentrated flow in medium-size rills. The channelling of the surface runoff in rills on the Sentinel Butte Formation probably decreases the rate of infiltration of water, thus increasing overall slopewash.

Table 5.--The angle of slope and the shape of the hillslope surface in the immediate vicinity of the rods of grids 1, 2, and 3.

		S.W.-facing hillslope Tongue River Formation Grid 1	N.E.-facing hillslope Tongue River Formation Grid 2	W.-facing hillslope Sentinel Butte Formation Grid 3
Average slope		31 ± 13	34 ± 10	35 ± 16
% of rods in the bottom of a rill	Large rill 4 to 12 inches deep	0	0	11
	Medium rill 2 to 4 inches deep	4	1	38
	Small rill less than 2 inches deep	0	0	10
% of rods on the side of a rill				
Medium rill 2 to 4 inches deep		0	0	9
% of rods not directly associated with a rill		96	99	32

### Hillslope Sediment Properties

Hillslope sediment properties that affect hillslope processes are (1) particle size and (2) clay mineralogy.

(1) The Tongue River Formation in the Buffalo Creek basin has an average of 7 percent less sand and 10 percent more silt than the Sentinel Butte Formation as indicated by laboratory measurements (Table 6). Because surface runoff erodes sand more readily, the more rapid removal of the sand from the Sentinel Butte Formation might cause a higher rate of hillslope lowering by slopewash on this formation. The lower content of sand in the Tongue River Formation reduces the rate of hillslope lowering by slopewash. To check the possibility that sediment containing a higher percentage of sand might have a higher erosion rate, the average rate of hillslope lowering by slopewash for each row of grid 1, 2, and 3 was plotted with the percentage of sand in the sediment as measured at each row. Again the coefficient of correlation indicated no correlation.

(2) The total clay fraction in both formations is composed of the following clay mineral in order of decreasing importance: montmorillonite, mica, mixed mica/montmorillonite, chlorite and kaolinite (Table 7). Chlorite and kaolinite occur only in minor amounts. The Sentinel Butte Formation has about 9 percent more clay minerals than the Tongue



Table 6.--Particle-size data for grids 1, 2, and 3.

Particle Size (Percent)	Tongue River Formation			Sentinel Butte Formation
	Grid 1	Grid 2		Grid 3
	16 samples	15 samples		32 samples
	Average			
Clay	40 ± 15	36	32 ± 14	40 ± 17
Silt	49 ± 8	49	48 ± 13	39 ± 16
Sand	11 ± 7	14	19 ± 17	21 ± 18

Table 7.--Average mineralogical composition of the Tongue River and Sentinel Butte Formations in Buffalo Creek basin as determined by x-ray analysis.

	Tongue River Formation Grids 1 and 2 6 samples	Sentinel Butte Formation Grid 3 6 samples
% Mica	$3.6 \pm 1.0$	$3.8 \pm 0.4$
% Plagioclase	$6.2 \pm 1.7$	$15.6 \pm 3.3$
% Orthoclase	$4.3 \pm 1.7$	$3.4 \pm 3.4$
% Quartz	$29.0 \pm 3.0$	$24.8 \pm 3.8$
% Calcite	$6.0 \pm 2.0$	$3.4 \pm 1.0$
% Dolomite	$16.2 \pm 3.2$	$6.0 \pm 1.8$
% Clay Minerals	$34.4 \pm 17.7$	$42.8 \pm 6.4$

River Formation. Because most of this clay content is montmorillonite, the change in the exposed length of the rods without washers in the Sentinel Butte Formation is greater than for the rods in the Tongue River Formation (Figures 14 and 15).

#### Permeability

The measurements for the rates of infiltration and percolation of water through the hillslope sediment were made in July 1969 (Table 8). The results therefore should not be taken as representative for the entire year. But the July measurements indicate important differences between the two formations. From the rates of infiltration and percolation in table 8 it can be seen that the greater part of the water falling on the slightly permeable surface of the Sentinel Butte Formation becomes surface runoff. The greater part of the rain falling on the more highly permeable surface of the Tongue River Formation infiltrates through the surface and percolates downward through the sediment. The higher rate of surface runoff on the Sentinel Butte Formation is the cause of the higher rate of hillslope lowering by slopewash in comparison to the rate on the Tongue River Formation. In comparing the rate of percolation and infiltration between the opposing hillslopes of the Tongue River Formation, the southwest-

Table 8.--The rate of infiltration and percolation of the Tongue River and Sentinel Butte hillslopes in Buffalo Creek basin.

	S.W.-facing hillslope Tongue River Formation Grid 1	N.E.-facing hillslope Tongue River Formation Grid 2	W.-facing hillslope Sentinel Butte Formation Grid 3
Infiltration gal./hour	$0.44 \pm 0.17$	$0.79 \pm 0.60$	$0.15 \pm 0.16$
Percolation gal./hour	$2.32 \pm 11.84$	$0.76 \pm 1.60$	$0.32 \pm 0.52$

facing hillslope has a greater degree of surface runoff and therefore a higher rate of hillslope lowering by slopewash. This is in agreement with the rates of hillslope lowering by slopewash for grid 1 and 2.

The high rate of hillslope lowering by slopewash on the Sentinel Butte Formation in part causes hard, unweathered sediment to exist immediately beneath the ground surface. Soil creep resulting from crystal growth or expansion and contraction of swelling-clay minerals is reduced because of the low infiltration and percolation rates in this formation. On the Tongue River hillslopes, the lower rate of hillslope lowering by slopewash and the high rates of infiltration and percolation result in a weathered zone up to 4 feet deep. This was easily noticed when digging the soil-creep stations and pounding in the 4-foot rods. The loose sediment at the surface is easily influenced by the mechanisms initiating soil creep. The northeast-facing hillslopes on the Tongue River Formation have more soil moisture because of their orientation. Therefore, these hillslopes are more susceptible to soil creep than the southwest-facing hillslopes (Figure 17).

Seepage at the seepage face results from the lateral movement of water along a surface separating an upper zone of higher permeability from a lower zone of reduced

permeability. The water moves laterally until it intersects the surface at a free face. The lateral movement of water may result from permeable valley fill overlying less permeable Tongue River sediment or weathered Tongue River sediment overlying less weathered Tongue River sediment. More often an impermeable layer develops from the deposition of slopewash sediment in desiccation cracks or in pore spaces within weathered sediment. This washed-in sediment has the appearance of a fairly well-developed illuviated horizon of a soil profile.

#### Vegetation

The bare hillslopes of the Sentinel Butte Formation result in a high rate of surface runoff, which intensifies slopewash (Figure 7). The denser vegetation on the Tongue River Formation increases the infiltration of surface runoff causing a decrease in slopewash (Figures 5 and 6). The denser vegetation of the northeast-facing hillslope of the Tongue River Formation explains the lower rate of hillslope lowering by slopewash compared with the southwest-facing hillslope.

#### Precipitation

The precipitation during the first year of measurement was 14.95 inches and during the second year 20.57 inches.

The erosion rates for these intervals are given in table 9. The greater precipitation during the second year of measurement resulted in a greater lowering of the hillslope surface by slopewash. Because most of the rain occurs as heavy showers between April and August, the higher rates of hillslope lowering by slopewash occur within these months (Figures 2 and 16).

Table 9.--The rate of lowering of the hillslopes on the Tongue River and Sentinel Butte Formations in Buffalo Creek basin for each year of study.

	S.W.-facing hillslope Tongue River Formation Grid 1	N.E.-facing hillslope Tongue River Formation Grid 2	W.-facing hillslope Sentinel Butte Formation Grid 3
Erosion in Inches			
July 15, 1967 to August 4, 1968	0.06	0.00	0.16
August 4, 1968 to July 29, 1969	0.23	0.22	0.65



SEDIMENT YIELD FROM BUFFALO CREEK BASIN,  
JUNE TO JULY 1969

Introduction

The sediment yield from Buffalo Creek basin is equal to the sediment yield from the hillslopes minus the sediment deposited on the valley bottom.

Hillslope Sediment Yield

The rates of slopewash from June to July 1969 were  $0.02 \pm 0.11$  inch at grid 1,  $0.05 \pm 0.05$  inch at grid 2, and  $0.23 \pm 0.10$  inch at grid 3. Using these rates of hillslope lowering and the square footage of the hillslopes as given in table 4, the total sediment yield from the hillslopes in Buffalo Creek basin is 16,000 cubic feet of sediment.

Valley-Bottom Sedimentation

The average rate of deposition on the valley bottom from June to July 1969 was  $0.33 \pm 0.29$  inch. The surface of the valley bottom is about 217,600 square feet. Therefore, approximately 6,000 cubic feet of sediment were deposited on the valley bottom during this time.

Calculation of Drainage Basin Sediment Yield

The sediment yield from Buffalo Creek basin from June to July 1969 is equal to the 16,000 cubic feet of sediment

from the hillslopes minus the 6,000 cubic feet of sediment deposited on the valley bottom or 10,000 cubic feet. Therefore, approximately 62 percent of the sediment yield from the hillslopes left Buffalo Creek basin and entered Jones Creek. The remaining 38 percent remained in Buffalo Creek basin.

#### Predicted Drainage Basin Sediment Yield

Hadley and Schumm (1961) compared the sediment yield and drainage area of 73 small drainage basins in the Cheyenne River basin in eastern Wyoming. According to their findings, the 0.13 square miles of Buffalo Creek basin should yield approximately 51,000 cubic feet per square mile per year. As stated previously, approximately 62 percent of the hillslope sediment yield from slopewash left Buffalo Creek basin during June and July 1969. Assuming that the magnitude of this figure is representative for an entire typical year, the total sediment yield per year from the basin is approximately 200,000 cubic feet per square mile. This value falls just on the edge of the scatter points indicated by Hadley and Schumm.

Hadley and Schumm also show the relation of mean annual sediment yield to relief ratio in 14 small drainage basins underlain by the Fort Union Formation in eastern Wyoming.

The relief of Buffalo Creek basin is 300 feet and its length is 3,400 feet. The relief ratio is therefore 0.09 and the predicted sediment yield interpolated from Hadley and Schumm's graph is considerably higher than the actual or the predicted yield as obtained from the drainage area and sediment yield relationship. The reason for the apparent high relief ratio and the correspondingly low sediment yield for Buffalo Creek basin is unknown.

The stratigraphy of the alluvial fills in Jones Creek indicates that erosion has predominated on the valley bottom of Jones Creek from 1935 (Hamilton, 1967). A comparison of the dissection of the valley bottom of the tributary basins of Jones Creek indicates that these tributaries do not contribute sediment to the valley bottom of Jones Creek at corresponding times. Therefore, the deposition in Buffalo Creek basin is not contemporaneous with deposition on the valley bottom of Jones Creek.

The rate of sediment production from Buffalo Creek basin cannot be applied to larger regions or even to all of the Little Missouri Badlands because sediment yield is a function of drainage basin size and relief ratio (Hadley and Schumm, 1961). However, the hillslope erosion rates presented in this study are probably representative of hillslope erosion throughout the Little Missouri Badlands.

## SUMMARY

In the study area, the lowering of the hillslope by slopewash is the most important hillslope process on the Tongue River and Sentinel Butte Formations. Slopewash on the Sentinel Butte Formation is approximately 3 times greater than on the Tongue River Formation. Part of the reason for this is that the Sentinel Butte Formation has a much lower rate of infiltration and percolation and a resulting higher rate of surface runoff than the Tongue River Formation. Slopewash is slightly higher on the southwest-facing Tongue River hillslopes than on the northeast-facing Tongue River hillslopes because of more vegetation on the northeast-facing hillslopes. Slopewash contributes 99.9 percent of the total sediment yield from the hillslopes to the valley bottom.

In the study area, soil creep is an active hillslope process only on the Tongue River Formation, and it is mainly restricted to the northeast-facing hillslopes. However, the sediment yield from soil creep is minor in comparison to the sediment yield by slopewash.

In the study area, seepage-step erosion is an active hillslope process on the Tongue River Formation, but the sediment yield from this process is also minor in comparison to slopewash.

## RECOMMENDATIONS

The rod and washer technique was successful in measuring slopewash. The correction for expansion of surficial sediment because of ice crystal growth or hydration of montmorillonite can be made when using a rod and washer but not when using a rod. The number of rods in each grid pattern was sufficient to obtain representative rates of hillslope erosion, however, the length of the rods with washers might be increased to 4 feet. This would help insure against any possibility of loosening of the rod by frost heaving.

The burial of plastic or glass beads along a line established by two cotter pins was a successful technique for measuring soil creep. Nonrustable cotter pins should be used to prevent the corrosion of the head of the pin.

The technique used for seepage-step retreat appears to be satisfactory.

If at all possible, remeasurements of erosion devices should be at least semi-annual and, especially for slopewash, after every major period of surface runoff. Information on the precision of all measurements should be included as part of every data list.

The importance of tunnelling should be fully investigated in any expansion of the current project in Buffalo Creek

Formation and the rates of arroyo retreat should also be analyzed. Beyond Buffalo Creek basin, rates of erosion and deposition in other drainage basins on the Sentinel Butte and Tongue River Formations should be obtained by establishing additional erosion sites. This is desirable because aerial photographs indicate the possibility that the small tributary basins of Jones Creek may not necessarily contribute sediment to this creek at corresponding periods of times. This possibility should be analyzed for it affects the relationship of total sediment yield under differing climatic conditions for larger drainage basins such as Jones Creek. Of perhaps more importance, erosion sites should be established on other formations and in other topographic settings in western North Dakota to provide data on regional rates of hillslope erosion and denudation. Study of rates of deposition in stock ponds or reservoirs in western North Dakota should be undertaken and resulting data correlated with the sediment yield for the corresponding drainage basins. Any bottom surveys of reservoirs such as Garrison Reservoir should be continued and correlated with regional rates of denudation.

APPENDICES

# APPENDIX A

Slopewash data in inches--4-foot and 2-foot iron rods. positive numbers indicate deposition and negative numbers indicate erosion. The estimated precision of each measurement is  $\frac{1}{32}$  inch.

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

## Profile 1

### Rod 0

4-foot	+0.56	*----	-0.44	+0.31	-0.25	-0.63	-0.44
2-foot	+0.56	----	+0.19	+0.13	-0.56	+0.06	+0.38

### Rod 1

4-foot	+0.25	0.00	+0.13	+0.31	-0.31	+0.19	+0.56
2-foot	+0.31	-1.38	+1.44	-0.06	-0.31	+0.19	+0.19

### Rod 2

4-foot	+0.63	-0.56	+0.19	0.00	-0.31	-0.13	-0.19
2-foot	+0.19	-0.31	+0.13	+0.13	-0.13	+0.25	+0.25

### Rod 3

4-foot	+0.19	-0.06	-0.06	-0.19	0.00	+0.06	-0.06
2-foot	-0.06	-0.06	-0.13	+0.06	-0.13	-0.06	-0.13

### Rod 4

4-foot	+0.81	+0.50	-0.13	0.00	+0.06	0.00	+1.25
2-foot	+0.38	-0.44	+0.56	-0.19	-0.31	+0.06	+0.06

### Rod 5

4-foot	+0.75	-1.44	-0.13	-0.06	0.00	-0.63	-1.38
2-foot	-0.06	-0.13	-0.88	+0.13	-0.44	-0.81	-2.06

\* Dashed line indicates no measurement taken.



7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Rod 6

4-foot	+0.19	-0.38	+0.19	-0.13	-0.25	-0.50	-0.88
2-foot	+0.31	-0.94	-0.38	0.00	+0.06	-0.25	-0.19

Rod 7

4-foot	+0.31	-0.06	+0.13	+0.19	-0.06	-0.13	+0.38
2-foot	+0.56	-0.38	+0.06	0.00	-1.00	-1.25	-2.00

Rod 8

4-foot	0.00	0.00	+0.06	-0.06	-0.25	+0.31	+0.06
2-foot	-0.19	+0.06	-0.06	0.00	-0.06	-0.19	-0.44

Rod 9

4-foot	+0.50	+0.13	-0.19	+0.13	-1.25	-1.13	+1.81
2-foot	+0.06	-0.06	+0.19	+0.06	-0.06	-0.06	+0.13

Rod 10

4-foot	0.00	-0.06	+0.13	-0.13	0.00	+0.13	+0.06
2-foot	+0.56	-0.06	+0.13	-0.13	0.00	+0.06	+0.56

Rod 11

4-foot	+0.13	-0.69	-0.06	+0.13	-0.25	+0.13	-0.63
2-foot	+0.06	-0.38	-0.13	+0.50	-0.13	-0.56	-0.63

Rod 12

4-foot	+0.44	+0.13	-0.25	+0.06	-0.19	+0.13	+0.31
2-foot	+0.06	0.00	+0.13	+0.06	-0.19	-0.69	-0.63

Rod 13

4-foot	-0.13	-0.13	+0.13	+0.81	-0.25	-0.06	+0.38
2-foot	+0.13	+0.13	0.00	+0.06	0.00	+0.19	+0.50

Rod 14

4-foot	0.00	0.00	-0.25	0.00	+0.25	+0.06	+0.06
2-foot	+0.19	-0.06	0.00	+0.13	-0.13	0.00	+0.13

Rod 15

4-foot	0.00	0.00	-0.13	+0.13	-0.06	+0.06	0.00
2-foot	+0.13	0.00	0.00	+0.06	-0.06	-0.06	+0.06

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

## Rod 16

4-foot	----	+0.06	+0.06	-0.06	+0.06	0.00	+0.13
2-foot	----	+0.19	-0.94	+1.00	+0.06	+0.06	+0.38

## Rod 17

4-foot	+0.06	-0.06	+0.56	-0.81	+0.25	0.00	0.00
2-foot	0.00	+0.25	0.00	+0.06	+0.06	+0.06	+0.44

## Rod 18

4-foot	0.00	-0.31	+0.44	-0.06	-0.56	-0.13	-0.63
2-foot	0.00	+0.38	-0.19	+0.19	-0.13	-0.19	+0.06

## Rod 19

4-foot	0.00	+0.75	0.00	-0.13	+0.63	+0.06	+1.31
2-foot	+0.06	+0.69	-0.19	+0.13	0.00	+0.13	+0.81

## Rod 20

4-foot	+0.19	+0.06	+0.13	0.00	0.00	+0.13	+0.50
2-foot	+0.06	+0.19	+0.19	-0.13	-0.19	+0.06	+0.56

## Profile 2

## Rod 21

4-foot	-0.06	-0.13	+0.13	+0.06	+0.19	+0.19	+0.38
2-foot	-0.06	+0.19	0.00	-0.13	-0.19	+0.19	0.00

## Rod 22

4-foot	-0.25	+0.13	+0.13	+0.06	-0.81	+0.13	+0.25
2-foot	-0.25	0.00	-0.06	-0.13	+0.19	+0.25	0.00

## Rod 23

4-foot	-0.13	0.00	-0.13	+0.13	0.00	+0.44	+0.31
2-foot	+0.13	+0.56	+0.06	+0.13	-0.13	+0.13	+0.88

## Rod 24

4-foot	0.00	0.00	+0.44	0.00	-0.06	+0.25	+0.63
2-foot	0.00	+0.25	+0.69	0.00	-0.13	+0.06	+0.88

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

## Rod 25

4-foot	-0.19	+0.31	+0.19	-0.06	+0.06	+0.31	+0.44
2-foot	+0.13	-0.13	+0.25	-0.06	+0.31	-0.25	+0.75

## Rod 26

4-foot	-0.06	+0.06	+0.38	-0.38	+0.38	+0.06	+0.44
2-foot	+0.25	+0.31	-0.06	-0.25	+0.31	0.00	+0.56

## Rod 27

4-foot	----	+0.63	-0.06	-0.25	+0.06	0.00	+0.38
2-foot	----	-0.13	+0.56	-0.06	0.00	-0.13	+0.25

## Rod 28

4-foot	0.00	-0.75	-0.19	+0.31	-0.50	+0.13	-1.00
2-foot	+0.13	-0.50	+0.38	0.00	+0.06	0.00	+0.06

## Rod 29

4-foot	-0.50	-0.13	+0.44	+0.13	+0.06	0.00	0.00
2-foot	+0.13	0.00	+0.13	+0.06	+0.31	-0.31	+0.31

## Rod 30

4-foot	-0.19	+0.13	+0.06	-0.25	+0.13	+0.19	+0.06
2-foot	-0.13	+0.31	+0.06	-0.06	0.00	+0.06	+0.25

## Rod 31

4-foot	-0.13	+0.25	+0.13	-0.06	+0.13	+0.06	+0.38
2-foot	+0.19	-0.13	-0.13	-0.25	+0.13	+0.06	-0.13

## Rod 32

4-foot	-0.19	-0.19	-0.13	+0.19	0.00	+0.06	-0.25
2-foot	+0.25	+0.06	-0.13	-0.19	-0.06	0.00	-0.06

## Rod 33

4-foot	+0.31	+0.56	-0.06	+0.19	-0.13	-0.06	+0.81
2-foot	+0.25	-0.06	-0.19	+0.13	-0.06	0.06	0.00

## Rod 34

4-foot	+0.25	-0.25	-0.06	+0.19	-0.06	+0.06	+0.13
2-foot	+0.19	+0.19	0.00	+0.06	0.00	0.00	+0.44

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

## Rod 35

4-foot	+0.19	+0.06	+0.25	-0.13	+0.06	0.00	+0.44
2-foot	+0.25	-0.06	----	----	----	0.00	+0.19

## Profile 3

## Rod 100

4-foot	+0.81	-0.75	+0.06	+0.19	-0.50	+0.25	+0.06
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## Rod 101

4-foot	+0.44	-0.25	+0.13	+0.31	-0.31	+0.06	+0.38
2-foot	+0.44	-0.25	+0.31	+0.19	-0.44	-0.06	+0.19

## Rod 102

4-foot	0.00	-0.19	+0.13	+0.06	-0.13	0.00	-0.13
2-foot	+0.69	-0.13	-0.38	+0.06	+0.44	-0.13	+0.56

## Rod 103

4-foot	+0.31	+0.06	+0.06	-0.13	+0.19	-0.06	+0.44
2-foot	0.00	0.00	+0.50	-0.19	-0.06	-0.06	+0.19

## Rod 104

4-foot	+0.25	+0.06	+0.31	-0.75	+0.13	-0.06	-0.06
2-foot	+0.50	-0.13	0.00	-0.19	-0.31	0.00	-0.13

## Rod 105

4-foot	+0.56	-0.31	0.00	-0.06	-0.31	+0.13	0.00
2-foot	+0.13	+0.75	-0.94	-0.06	-0.50	-0.25	-0.88

## Rod 106

4-foot	+0.38	-0.13	-0.19	+0.25	+0.19	-0.25	+0.25
2-foot	+0.13	+0.19	+0.06	+0.13	-0.13	-0.13	+0.25

## Rod 107

4-foot	0.00	-0.50	+0.50	+0.06	-0.13	+0.13	+0.06
2-foot	+0.13	-0.25	+0.44	-0.19	+0.06	+0.25	+0.44

## Rod 108

4-foot	----	----	-0.13	+0.13	----	----	0.00
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7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Rod 109

4-foot	+0.19	0.00	+0.13	+1.19	-1.00	+0.31	+0.81
2-foot	----	+0.31	+0.25	0.00	+0.06	+0.13	+0.75

Rod 110

4-foot	+0.25	-0.13	+0.88	-0.06	-0.44	+0.13	+0.63
2-foot	+0.25	-0.63	+2.13	-1.06	-0.94	-0.06	-0.31

Rod 111

4-foot	0.00	-0.13	+1.06	+0.56	-2.19	-0.31	-1.00
2-foot	+0.19	+0.06	+0.06	+0.06	+0.13	0.00	+0.50

Rod 112

4-foot	+0.06	+0.19	+0.06	-0.19	+0.13	+0.69	+0.94
2-foot	+0.44	-0.19	+0.06	-0.06	+0.13	+0.31	+0.69

Rod 113

4-foot	-0.19	0.00	+0.06	0.00	-0.13	-1.19	-1.44
2-foot	+0.13	-0.19	+0.06	+0.13	-0.06	+0.06	+0.13

Rod 114

4-foot	-0.25	-0.31	-0.25	-0.06	0.00	0.00	-0.88
2-foot	+0.13	-0.06	0.00	-0.13	+0.06	0.00	0.00

Rod 115

4-foot	+0.06	-0.06	-0.06	+0.13	-0.19	+0.06	-0.06
2-foot	0.00	-0.13	0.00	0.00	+0.06	-0.06	-0.13

Rod 116

4-foot	-0.06	-0.50	+0.25	0.00	0.00	0.00	-0.31
2-foot	+0.56	-0.44	+0.13	0.00	+0.06	-0.06	+0.25

Rod 117

4-foot	-0.19	0.00	-0.06	-0.13	+0.13	+0.25	0.00
2-foot	+0.19	-0.25	+0.31	-0.19	0.00	0.00	+0.06

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

## Profile 4

Rod 119							
4-foot	+0.13	0.00	-0.63	+0.19	-0.31	-0.50	-1.13
2-foot	+0.25	-0.88	----	----	----	----	-0.63
Rod 120							
4-foot	+1.56	-1.06	+0.31	+0.13	-0.69	-0.25	0.00
2-foot	+1.19	-0.50	+0.38	+0.25	-0.31	-0.25	+0.75
Rod 121							
4-foot	+0.44	-0.63	-0.56	+0.25	-0.25	-0.38	-1.13
2-foot	+0.31	-0.69	-0.19	+0.06	-0.38	-0.25	-1.13
Rod 122							
4-foot	+0.81	-0.94	+0.44	-0.44	-0.44	-0.69	-1.25
2-foot	+0.06	-0.31	-0.25	+0.06	-0.19	-0.44	-1.06
Rod 123							
4-foot	-0.19	-0.06	-0.44	0.00	-0.06	-0.56	-1.31
2-foot	+0.06	-0.38	-0.63	+0.94	-0.88	-0.75	-1.63
Rod 124							
4-foot	-0.13	-0.44	-0.19	0.00	0.00	-0.31	-1.06
2-foot	0.00	-0.38	-0.25	+1.06	-1.06	-0.44	-1.06
Rod 125							
4-foot	+0.13	-0.31	-0.06	-0.13	0.00	-0.25	-0.63
2-foot	+0.19	-0.50	-0.19	+0.13	-0.31	-0.31	-1.00
Rod 126							
4-foot	+0.69	+0.06	+0.06	+0.06	-0.25	-0.25	+0.38
2-foot	+0.81	-1.88	+0.63	+0.25	-0.31	+0.50	0.00
Rod 127							
4-foot	+0.63	+0.44	-0.25	0.00	-0.06	-0.50	+0.25
2-foot	+0.63	-0.50	-0.13	+0.06	-0.19	+0.06	-0.06
Rod 128							
4-foot	-0.13	-0.31	-0.25	+0.06	+0.75	-1.38	-1.25
2-foot	-0.25	-0.13	-0.25	+0.06	-0.31	-0.38	-1.25

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

## Rod 129

4-foot	+0.19	-0.38	-0.69	-0.75	-0.31	-0.19	-0.75
2-foot	+0.13	-0.06	-0.31	+0.19	-0.31	-0.25	-0.63

## Rod 130

4-foot	-0.06	-0.38	-0.56	+0.06	-0.25	-1.50	-2.68
2-foot	-0.13	+0.31	0.00	0.00	-0.44	-0.63	-0.88

## Rod 131

4-foot	+0.25	+0.56	-0.31	-0.31	+0.38	-0.81	-0.25
2-foot	+0.06	-0.06	-0.31	+0.19	-0.13	-0.25	-0.50

## Rod 132

4-foot	+0.63	-1.87	-0.63	+0.19	-0.13	-0.38	-2.19
2-foot	+1.19	-0.19	+0.31	0.00	-0.25	-0.94	+0.13

## Rod 133

4-foot	+0.13	+0.25	-0.38	0.00	-0.06	+0.06	0.00
2-foot	+1.81	-0.38	-0.50	+0.19	-0.56	-0.50	+0.06

## Rod 134

4-foot	+0.31	0.00	0.00	-0.25	+0.13	-0.06	+0.13
2-foot	+0.50	+0.75	0.00	-0.13	+0.50	+0.31	+1.94

## Rod 135

4-foot	+0.69	-0.13	-0.38	+0.19	-0.13	-0.13	+0.13
2-foot	0.00	-0.19	-0.25	+0.06	-0.13	-0.06	-0.63

## Rod 136

4-foot	+0.06	-0.25	-0.13	+0.06	-0.25	-0.19	-0.69
2-foot	0.00	+0.13	+0.13	0.00	-0.19	-0.19	-0.13

## Rod 137

4-foot	0.00	-0.06	+0.81	-0.31	+0.06	-1.13	-0.63
2-foot	-0.06	-0.25	-0.25	+0.06	-0.13	-0.25	-0.88

## Rod 138

4-foot	-0.31	-0.19	-0.44	+0.06	-0.13	-0.25	-1.25
2-foot	-0.19	-0.19	-0.13	0.00	0.00	-0.13	-0.63

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Rod 139

4-foot	-0.06	-0.25	-0.19	+0.13	-0.13	-0.19	-0.69
2-foot	-0.13	-0.19	-0.13	0.00	-0.19	-0.31	-0.94

Rod 140

4-foot	+1.31	-0.63	+0.19	+0.31	-0.63	-0.19	+0.38
2-foot	+0.19	-0.38	+0.31	-0.25	-0.19	+0.69	+0.44

Rod 141

4-foot	+0.94	-1.50	+0.19	+1.38	-1.13	-0.31	-0.44
2-foot	-0.13	-0.63	-0.06	-0.06	-0.88	-0.31	-2.06

Rod 142

4-foot	0.00	-0.31	-0.31	+1.31	-1.44	-0.31	-0.44
2-foot	+0.25	-0.38	-0.19	-0.06	-0.31	-0.31	-1.38



# APPENDIX B

Slopewash data in inches--6-inch nails. Positive numbers indicate deposition and negative numbers indicate erosion. The estimated precision of each measurement is  $\frac{1}{32}$  inch.

7/67	6/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

## Grid 1

### Row 2

Nail	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.00	+0.13	-0.06	0.00	0.00	0.00	+0.06
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	0.00	+0.13	0.00	0.00	0.00	0.00	+0.13
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	+0.13	-0.06	+0.19	0.00	0.00	+0.25

### Row 3

Nail	1	0.00	+0.19	-0.13	-0.06	0.00	0.00	0.00
	2	0.00	-0.06	0.00	-0.19	0.00	0.00	-0.25
	3	0.00	+0.19	-0.13	-0.13	0.00	0.00	+0.06
	4	0.00	0.00	0.00	-0.19	-0.19	0.00	-0.38
	5	-0.06	0.00	-0.13	0.00	0.19	0.38	0.75
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00

### Row 4

Nail	1	0.00	-0.44	0.00	-0.13	-0.06	0.00	-0.63
	2	0.00	-0.50	0.00	-0.13	0.00	0.00	-0.63
	3	0.00	-0.38	+0.81	-1.06	-0.25	0.00	-0.86
	4	0.00	0.00	0.00	-0.25	+0.06	0.00	+0.06
	5	----	----	----	----	+0.06	0.00	+0.06

\* Dashed line indicates no measurement taken.

7/67	6/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 5

Nail	1	0.00	+0.19	0.00	0.00	-0.38	+0.13	-0.06
	2	0.00	0.00	0.00	0.00	0.00	+0.56	+0.56
	3	0.00	-0.31	+0.44	-0.06	-0.13	-1.13	-1.19
	4	0.00	-0.19	-0.19	-0.19	-0.13	-0.19	-0.88
	5	0.00	0.00	-0.44	-0.06	-0.31	-0.13	-0.94
	6	----	+0.75	----	----	0.00	----	+0.75

Row 6

Nail	1	0.00	-0.63	0.00	0.00	-0.25	-0.50	-1.38
	2	0.00	0.00	-0.69	+0.06	0.00	-0.50	-1.06
	3	0.00	0.00	-0.13	0.00	-0.25	-0.25	-0.63
	4	0.00	0.00	0.00	-0.13	-0.38	-0.25	-0.75
	5	0.00	0.00	0.00	-0.19	-0.06	0.00	-0.25
	6	0.00	-0.50	-0.38	0.00	-0.19	-0.44	-1.50

Row 7

Nail	1	0.00	-0.06	0.00	0.00	-0.13	-0.06	-0.25
	2	0.00	-0.50	-0.13	-0.13	-0.31	-0.19	-1.25
	3	0.00	+0.06	-0.06	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	-0.06	0.00	-0.06
	5	-0.13	-0.06	0.00	+0.25	-1.25	0.00	-1.19
	6	0.00	+0.06	0.00	+0.13	-0.13	0.00	+0.06

Row 8

Nail	1	0.00	-0.13	-0.13	0.00	-0.38	0.00	-0.63
	2	0.00	-0.25	-0.06	0.00	-0.63	-0.38	-1.31
	3	0.00	0.00	-0.06	0.00	-0.38	-0.56	-1.00
	4	-0.13	0.00	0.00	0.00	0.00	-0.06	-0.19
	5	0.00	-0.06	0.00	0.00	-0.06	0.00	-0.13
	6	0.00	0.00	0.00	-0.06	-0.19	0.00	-0.25

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 9

Nail	1	0.00	-0.06	0.00	-0.06	-0.31	0.00	-0.44
	2	0.00	0.00	0.00	-0.13	0.00	0.00	-0.13
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	+0.06	+0.06	0.00	-0.13	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	-0.13	-0.44	0.00	-0.50	0.00	-1.06

Row 11

Nail	1	0.00	-0.25	0.00	-0.06	-0.13	0.00	-0.44
	2	0.00	+0.06	0.00	0.00	0.00	0.00	+0.06
	3	0.00	-0.13	0.00	0.00	-0.25	0.00	-0.38
	4	0.00	+0.06	0.00	-0.25	0.00	0.00	-0.19
	5	0.00	-0.50	0.00	0.00	-0.31	0.00	-0.81

Row 12

Nail	1	0.00	-0.63	0.00	0.00	-0.06	0.00	-0.69
	2	0.00	+0.19	0.00	0.00	0.00	0.00	+0.19
	3	0.00	-0.31	0.00	0.00	0.00	0.00	-0.31
	4	0.00	-0.38	-0.25	-0.13	-0.13	0.00	-0.75
	5	0.00	-0.06	0.00	0.00	-0.06	0.00	-0.13
	6	0.00	-0.13	0.00	0.00	0.00	0.00	-0.13

Row 13

Nail	1	0.00	+0.63	+0.25	-0.25	+0.44	+0.44	+1.51
	2	0.00	+0.38	+0.06	0.00	0.00	+0.13	+0.56
	3	0.00	0.00	0.00	0.00	-0.06	0.00	-0.06
	4	0.00	0.00	0.00	0.00	+0.19	+0.19	+0.38
	5	0.00	-0.50	0.00	0.00	-0.25	-0.19	-0.94
	6	0.00	0.00	0.00	-0.06	-0.19	0.00	-0.25

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 14

Nail	1	0.00	+0.06	-0.06	0.00	0.00	0.00	0.00
	2	0.00	+0.25	+0.13	0.00	0.00	0.00	+0.38
	3	0.00	-0.06	-0.06	0.00	+0.13	+0.13	+0.13
	4	0.00	-0.06	0.00	0.00	0.00	0.00	-0.06
	5	0.00	-0.19	0.00	-0.19	-0.25	-0.06	-0.69
	6	0.00	0.00	0.00	0.00	-0.06	0.00	-0.06

Row 15

Nail	1	0.00	+0.19	+0.06	+0.06	+0.19	+0.13	+0.63
	2	0.00	+0.06	+0.13	-0.06	+0.06	+0.25	+0.44
	3	0.00	+0.13	0.00	0.00	+0.06	+0.13	+0.25
	4	0.00	+0.13	0.00	0.00	+0.19	+0.19	+0.44
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	+0.06	+0.13	-0.19	+0.13	0.00	+0.13

Row 17

Nail	1	0.00	-0.25	-0.25	-0.13	-0.31	0.00	-0.94
	2	0.00	-0.06	0.00	-0.31	-0.31	0.00	-0.69
	3	0.00	-0.13	0.00	-0.13	-1.00	-0.13	-1.38
	4	0.00	-0.75	----	----	+0.06	+0.44	-0.25
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Row 20

Nail	1	0.00	+0.13	0.00	-0.31	+0.13	0.00	-0.06
	2	0.00	+0.25	+0.06	-0.75	+0.38	+0.13	+0.06
	3	0.00	+0.06	0.00	-0.19	+0.31	0.00	+0.19
	4	0.00	-0.13	----	-0.06	----	----	-0.19

Grid 2

Row 21

Nail	1	0.00	+0.44	0.00	-0.19	-0.06	0.00	-0.19
	2	0.00	0.00	----	-0.13	0.00	0.00	-0.13

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 22

Nail	1	0.00	+0.19	0.00	0.00	0.00	-0.13	+0.06
	2	0.00	0.00	0.00	-0.19	0.00	0.00	-0.19
	3	0.00	-0.19	0.00	0.00	0.00	-0.13	-0.31
	4	0.00	0.00	0.00	-0.13	0.00	0.00	-0.13
	5	0.00	0.00	0.00	0.00	0.00	-0.13	-0.13
	6	0.00	0.00	0.00	-0.19	-0.06	0.00	-0.25

Row 23

Nail	1	0.00	+0.38	0.00	-0.25	0.00	0.00	+0.13
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	0.00	-0.69	0.00	-0.06	0.00	0.00	-0.75
	4	0.00	0.00	0.00	0.00	-0.13	0.00	-0.13
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	-0.13	0.00	0.00	0.00	0.00	-0.13

Row 24

Nail	1	0.00	0.00	-0.31	0.00	0.00	-0.38	-0.69
	2	+0.13	0.00	0.00	-0.13	+0.31	-0.38	-0.06
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	-0.06	0.00	0.00	-0.06
	5	+0.13	0.00	-0.13	0.00	+0.25	0.00	+0.25
	6	+0.25	0.00	-0.06	0.00	0.00	-0.06	+0.13

Row 25

Nail	1	0.00	0.00	0.00	0.00	+0.06	-0.06	0.00
	2	0.00	0.00	0.00	-0.06	-0.06	-0.13	-0.25
	3	0.00	0.00	0.00	0.00	-0.50	0.00	-0.50
	4	+0.13	0.00	0.00	0.00	0.00	0.00	+0.13
	5	+0.19	0.00	0.00	0.00	0.00	0.00	+0.19
	6	0.00	-0.06	0.00	0.00	-0.13	0.00	-0.19

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 26

Nail	1	0.00	-0.50	0.00	0.00	-0.25	0.00	-0.75
	2	0.00	-0.13	0.00	-0.13	0.00	0.00	-0.25
	3	0.00	+0.06	0.00	-0.19	-0.06	0.00	-0.19
	4	0.00	-0.06	0.00	-0.06	0.00	0.00	-0.13
	5	-0.06	-0.06	0.00	0.00	0.00	0.00	-0.13
	6	0.00	0.00	-0.25	0.00	0.00	0.00	-0.25

Row 27

Nail	1	+0.50	0.00	-0.63	+0.30	-0.50	0.00	-0.25
	2	0.00	0.00	0.00	0.00	-0.19	0.00	-0.19
	3	0.00	-0.13	0.00	-0.13	0.00	0.00	-0.25
	4	0.00	+1.00	0.00	0.00	+0.25	-0.13	+1.13
	5	0.00	-0.25	-0.19	-0.44	-0.25	-0.13	-1.25
	6	0.00	0.00	0.00	0.00	0.00	-0.13	-0.13

Row 28

Nail	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	+0.06	0.00	+0.06
	3	0.00	0.00	0.00	-0.06	0.00	-0.13	-0.19
	4	0.00	0.00	-0.25	0.00	-0.19	0.00	-0.44
	5	0.00	0.00	0.00	0.00	0.00	-0.06	-0.06
	6	0.00	0.00	0.00	0.00	-0.06	0.00	-0.06

Row 29

Nail	1	0.00	0.00	+0.06	0.00	-0.06	0.00	0.00
	2	0.00	0.00	-0.06	-0.06	0.00	0.00	-0.13
	3	0.00	+0.19	0.00	-0.06	0.00	0.00	+0.13
	4	0.00	0.00	-0.19	0.00	+0.13	-0.06	-0.13
	5	0.00	0.00	-0.06	0.00	0.00	-0.06	-0.13
	6	0.00	0.00	-0.06	-0.06	-0.13	0.00	-0.25

7/67	4/68	8/68	11/68	4/69	6/69	7/69
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 30

Nail	1	0.00	0.00	-0.19	0.00	0.00	0.00	-0.19
	2	0.00	-0.25	0.00	0.00	-0.06	-0.06	-0.38
	3	0.00	-0.19	-0.13	0.00	0.00	-0.50	-0.81
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5	+0.25	0.00	-0.13	0.00	0.00	-0.25	-0.13

Row 31

Nail	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	-0.06	0.00	0.00	0.00	-0.06
	3	0.00	0.00	-0.06	-0.44	0.00	0.00	-0.50
	4	0.00	0.00	-0.06	0.00	0.00	0.00	-0.06
	5	0.00	0.00	-0.06	0.00	-0.06	-0.06	-0.19
	6	0.00	-0.62	-0.31	0.00	-0.94	0.00	-1.87

Row 32

Nail	1	0.00	0.00	-0.06	-0.31	0.00	0.00	-0.38
	2	0.00	0.00	-0.13	-0.13	0.00	0.00	-0.25
	3	0.00	0.00	0.00	-0.06	0.00	0.00	-0.06
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	-0.06	0.00	0.00	0.00	-0.06
	6	+0.06	+0.06	-0.06	0.00	0.00	0.00	+0.06

Row 33

Nail	1	0.00	-0.25	-0.25	0.00	-0.50	0.00	-1.00
	2	0.00	0.00	-0.25	0.00	0.00	-0.19	-0.44
	3	0.00	0.00	0.00	-0.06	0.00	0.00	-0.06
	4	0.00	0.00	-0.19	0.00	-0.13	-0.25	-0.56
	5	0.00	0.00	-0.06	0.00	0.00	0.00	-0.06

Row 34

Nail	1	0.00	0.00	-0.39	0.00	-0.13	0.00	-0.50
	2	0.00	0.00	0.00	0.00	-0.19	-0.50	-0.69
	3	0.00	+0.06	-0.06	0.00	-0.25	-0.19	-0.44
	4	0.00	+0.06	-0.13	0.00	0.00	0.00	-0.06
	5	0.00	-0.13	-0.31	0.00	0.00	0.00	-0.44

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 35

Nail	1	0.00	0.00	0.00	-0.06	0.00	0.00	-0.06
	2	0.00	0.00	-0.25	0.00	0.00	0.00	-0.25

Grid 3

Row 119

Nail	1	0.00	0.00	-0.06	-0.75	0.00	-0.19	-1.00
	2	0.00	-0.25	-0.06	-0.31	-0.63	-0.19	-1.44
	3	+0.13	-0.63	+0.13	-0.31	0.00	-0.38	-1.06
	4	0.00	0.00	+0.56	+0.38	-1.06	-0.50	-0.63
	5	+0.50	-0.13	0.00	----	-0.94	-0.56	-1.13
	6	+1.00	-1.06	----	----	----	----	-0.06

Row 120

Nail	1	0.00	-0.31	-0.13	-0.13	-0.25	-0.19	-1.00
	2	0.00	+0.13	-1.13	0.00	-0.13	-0.63	-1.75
	3	0.00	-0.13	-0.44	-0.13	0.00	-0.06	-0.75
	4	+0.06	+1.94	-0.19	0.00	-0.94	-0.50	+0.38
	5	0.00	+0.44	----	----	-0.50	-0.13	-0.19

Row 121

Nail	1	-0.13	-0.13	-0.38	-0.06	0.00	-0.25	-0.94
	2	-0.50	0.00	-0.13	-0.06	0.00	-0.19	-0.88
	3	+0.13	-0.25	+0.38	-0.13	-0.25	-0.06	-0.19
	4	+0.94	-0.88	0.00	0.00	-0.50	+0.44	0.00
	5	0.00	-0.19	-0.13	0.00	-0.38	-0.13	-0.81
	6	0.00	-0.50	0.00	0.00	-0.25	-0.13	-0.88

Row 122

Nail	1	-0.50	0.00	-0.19	0.00	0.00	-0.31	-1.00
	2	-0.13	0.00	-0.31	-0.13	-0.06	-0.13	-0.75
	3	0.00	-0.19	0.00	0.00	0.00	-0.38	-0.56
	4	0.00	-0.13	-0.19	0.00	-0.06	-0.19	-0.56
	5	+0.94	-1.94	+0.68	+0.56	-0.94	-0.38	-1.06
	6	+0.19	-0.19	-0.13	0.00	-0.56	-0.13	-0.81



7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	8/68	11/68	4/69	6/69	7/69	7/69

Row 123

Nail	1	0.00	-0.25	-0.13	0.00	-0.25	-0.19	-0.81
	2	0.00	0.00	-0.13	-0.13	+0.13	-0.31	-0.44
	3	+0.19	-0.19	+0.56	-0.06	-0.63	-0.69	-0.81
	4	-0.13	0.00	-0.13	0.00	-0.19	-0.25	-0.69
	5	+0.50	-0.25	0.00	0.00	-0.38	-0.38	-0.50
	6	0.00	-0.38	0.00	-0.44	0.00	-0.06	-0.88
	7	-0.13	-0.19	-0.69	0.00	-0.38	-0.31	-1.69
	8	0.00	-0.25	-0.56	0.00	-0.13	-0.13	-1.06

Row 124

Nail	1	-0.25	-0.19	-0.19	0.00	-0.19	-0.19	-1.00
	2	-0.06	-0.06	-0.38	+0.06	+0.06	-0.31	-0.69
	3	0.00	-0.25	-0.25	0.00	-0.13	-0.38	-1.00
	4	0.00	-0.25	-0.69	+0.13	-0.25	-0.06	-1.13
	5	+0.06	+0.19	+0.06	0.00	-0.13	+0.13	+0.33
	6	-0.06	-0.25	-0.38	-0.63	-0.25	-0.75	-2.31

Row 125

Nail	1	+0.13	+0.38	-1.06	-0.13	-1.25	-0.31	-2.25
	2	+0.25	+0.63	-0.50	+0.88	-1.00	-0.38	-0.13
	3	-0.13	-0.25	-0.38	0.00	-0.13	-0.69	-1.56
	4	+0.88	-1.06	+0.88	+0.31	-2.00	-0.19	-1.19
	5	+0.13	-0.38	-0.19	-0.13	0.00	-0.25	-0.81
	6	-0.13	-0.25	-0.25	0.00	-0.25	+0.38	-0.50
	7	+0.13	-0.13	-0.31	+0.31	+0.13	-1.06	-0.94
	8	0.00	+0.06	-0.19	0.00	+0.13	-0.50	-0.50

Row 126

Nail	1	-0.19	-0.38	-0.38	0.00	-0.13	-0.25	-1.31
	2	+0.19	0.00	-0.19	0.00	-0.31	0.00	-0.31
	3	+0.13	0.00	-0.31	+0.06	-0.13	-0.19	-0.44
	4	+0.06	-0.31	-0.13	0.00	-0.13	-0.25	-0.75
	5	+0.19	-0.44	-0.25	+0.50	-0.50	-0.13	-0.63
	6	-0.13	-0.13	-0.19	0.00	+0.19	-0.19	-0.44

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/48	8/68	11/68	4/69	6/69	7/69	7/69

## Row 128

Nail	1	-0.25	-0.13	-0.31	0.00	+0.19	-0.75	-1.25
	2	-0.31	-0.19	-0.38	0.00	-0.13	-0.25	-1.25
	3	-0.13	-0.50	0.00	0.00	-0.19	-0.06	-0.88
	4	0.00	-0.25	-0.31	0.00	-0.13	-0.38	-1.06
	5	-0.25	-0.31	-0.25	0.00	-0.06	-0.19	-1.06
	6	-0.25	-0.06	-0.19	0.00	-0.13	-0.25	-0.88

## Row 129

Nail	1	0.00	-0.50	-0.31	0.00	0.00	-0.50	-1.31
	2	-0.19	-0.31	-0.50	-0.06	-0.25	-0.44	-1.95
	3	-0.06	-0.44	-0.25	0.00	-0.13	-0.50	-1.38
	4	-0.06	-0.56	-0.31	0.00	-0.13	-0.25	-1.31
	5	-0.19	-0.31	-0.13	0.00	-0.13	-0.25	-1.00
	6	-0.13	-0.25	-0.25	0.00	-0.13	-0.25	-1.00
	7	-----	-----	-----	-----	-----	-0.06	-0.06

## Row 130A

Nail	1	0.00	-0.25	-0.19	0.00	0.00	-0.19	-0.63
	2	-0.19	-0.13	-0.25	0.00	0.00	-0.06	-0.63
	3	-0.50	-1.50	-0.06	0.00	-0.19	-0.25	-2.50
	4	-0.13	-0.13	-0.44	0.00	-0.06	-0.19	-0.94
	5	+0.06	-0.38	-0.31	0.00	-0.19	-0.25	-0.88
	6	-0.13	-0.38	-0.06	0.00	-0.25	-0.19	-1.00

## Row 130B

Nail	1	-0.06	-0.19	-0.31	0.00	0.00	-0.31	-0.88
	2	-0.13	-0.06	-0.44	0.00	-0.13	-0.19	-0.94
	3	-0.13	-0.13	-0.44	0.00	-0.13	-0.19	-1.00
	4	+0.06	-0.25	-0.50	+0.06	-0.19	-0.06	-0.88
	5	-0.13	0.00	-0.81	0.00	-0.13	-0.13	-1.18
	6	0.00	-0.06	-0.44	-0.25	+0.13	-0.06	-0.69

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	6/68	11/68	4/69	6/69	7/69	7/69

Row 131

Nail	1	-0.06	-0.19	-0.06	0.00	-0.13	-0.19	-0.63
	2	-0.13	-0.13	-0.25	0.00	0.00	-0.06	-0.56
	3	+0.50	0.00	-0.19	-0.44	-0.13	0.00	-0.25
	4	-0.13	-0.13	----	0.00	-0.06	-0.13	-0.44

Row 132

Nail	1	+0.06	-0.06	0.00	0.00	0.00	0.00	0.00
	2	0.00	-0.38	-0.63	0.00	-0.38	-0.25	-1.63
	3	-0.13	-0.13	-0.25	0.00	0.00	-0.38	-0.88
	4	-0.50	0.00	-0.13	0.00	0.00	-0.38	-1.00
	5	0.00	-0.19	-0.06	0.00	-0.13	-0.06	-0.44
	6	0.00	+0.13	-0.31	0.00	-0.19	-0.25	-0.63

Row 133-134

Nail	1	-0.25	0.00	-0.31	0.00	-0.13	0.00	-0.69
	2	0.00	-0.06	-0.50	0.00	+0.25	-0.13	-0.44
	3	+0.50	0.00	-0.25	0.00	-0.13	-0.44	-0.31
	4	+0.06	+0.06	-0.25	0.00	0.00	-0.06	-0.19

Row 135

Nail	1	+0.06	-0.19	-0.13	0.00	-0.31	0.00	-0.56
	2	+0.06	-0.13	-0.19	0.00	-0.38	-0.13	-0.88
	3	0.00	0.00	-0.31	0.00	0.00	-0.25	-0.56
	4	+0.25	-0.38	-0.25	0.00	0.00	-0.19	-0.56
	5	-0.13	-0.13	0.00	-0.06	0.00	-0.13	-0.44
	6	-0.13	-0.50	+0.25	0.00	0.00	-0.06	-0.44

Row 136

Nail	1	-0.06	-0.13	-0.19	0.00	-0.06	-0.13	-0.56
	2	0.00	-0.19	-0.31	0.00	0.00	-0.13	-0.62
	3	+0.06	0.00	-0.25	+0.13	-0.38	0.00	-0.44
	4	0.00	-0.50	-0.19	-0.06	-0.19	-0.13	-1.06

7/67	4/68	8/68	11/68	4/69	6/69	7/67
to	to	to	to	to	to	to
4/68	6/68	11/68	4/69	6/69	7/69	7/69

## Row 137

Nail	1	-0.06	-0.06	+0.63	0.00	-0.13	-1.25	-0.44
	2	-0.13	0.00	-0.06	-0.06	-0.13	-0.25	-0.63
	3	-0.31	-0.25	-0.38	0.00	0.00	0.00	-0.94
	4	-0.25	-0.25	-0.25	-0.44	-0.31	-0.38	-1.88
	5	-0.13	-0.13	-0.25	0.00	-0.13	-0.25	-0.88

## Row 138

Nail	1	+0.13	-0.25	-0.88	-0.06	-0.25	-0.31	-1.63
	2	0.00	+0.31	-0.44	-0.38	+0.13	-0.31	-0.69
	3	0.00	-0.44	-0.19	-0.31	-0.13	-0.06	-1.13
	4	-0.25	-0.06	-0.44	-0.38	-0.25	-0.50	-1.88
	5	0.00	+0.06	-0.50	-0.13	-0.06	-0.19	-0.81
	6	0.00	-0.31	-0.31	-0.38	0.00	0.00	-1.00

## Row 139

Nail	1	+0.13	+0.88	0.00	0.00	-0.63	-0.13	+0.44
	2	0.00	-0.50	-0.06	0.00	-0.44	-0.25	-1.25
	3	0.00	-0.13	-0.13	0.00	-0.13	-0.13	-0.50
	4	-0.13	-0.44	-0.25	0.00	-0.19	-0.13	-1.13
	5	-0.06	-0.25	-0.13	0.00	-0.13	-0.19	-0.75
	6	0.00	-0.50	-0.19	-1.00	0.00	-0.88	-2.56

## Row 141

Nail	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.00	+0.06	0.00	0.00	0.00	-0.13	-0.06
	3	----	+0.06	0.00	0.00	0.00	----	+0.06

## Row 142

Nail	1	0.00	0.00	0.00	0.00	-0.13	-0.44	-0.56
	2	-0.06	0.00	0.00	0.00	0.00	-0.13	-0.19
	3	-0.06	0.00	0.00	0.00	0.00	-0.38	-0.44
	4	----	0.00	0.00	0.00	0.00	0.00	0.00

# APPENDIX C

Seepage-step data in inches--Positive numbers indicate deposition perpendicular to the slope and negative numbers erosion. The estimated precision of each measurement is  $\frac{1}{32}$  inch.

4/68	6/68	8/68	11/68	4/69	6/69	4/68
to	to	to	to	to	to	to
6/68	8/68	11/68	4/69	6/69	7/69	7/69

## Site 1

Upper Rod-Tread	0.00	0.00	+0.19	0.00	+0.13	-0.06	+0.25
Lower Rod-Tread	0.00	0.00	0.00	0.00	0.00	-0.06	00.06
Rods-Seepage Face							
1	+0.06	-0.88	+0.69	-0.13	+0.06	-0.31	-0.31
2	+0.25	-0.25	-0.38	0.00	+0.06	-0.06	-0.38
Rods-Basal Slope	----	----	----	----	----	----	----
Upper Rod-Debris Slope	0.00	0.00	+0.19	0.00	-0.38	+0.13	-0.06
Lower Rod-Debris Slope	+0.06	+0.31	+0.13	-0.19	+0.25	+0.06	+0.63

## Site 2

Upper Rod-Tread	+0.38	-0.13	-0.13	+0.19	-0.25	0.00	+0.06
Lower Rod-Tread	+0.13	-0.06	0.00	-0.06	0.00	-0.06	-0.06
Rods-Seepage Face							
1	0.00	-0.13	-0.06	0.00	0.00	0.00	-0.19
2	+0.50	-1.31	-0.50	+0.44	-0.69	+0.06	-1.50
Rods-Basal Slope	----	----	----	----	----	----	----
Upper Rod-Debris Slope	+0.25	-0.56	-0.13	-0.13	+0.56	-0.06	-0.06
Lower Rod-Debris Slope	+0.13	+0.13	-0.25	0.00	+0.25	-0.13	+0.13

\* Dashed line indicates no basal slope at that site.

4/68	6/68	8/68	11/68	4/69	6/69	4/68
to	to	to	to	to	to	to
6/68	8/68	11/68	4/69	6/69	7/69	7/69

## Site 3

Upper Rod-Tread	+0.06	+0.13	+0.06	0.00	-0.13	0.00	+0.13
Lower Rod-Tread	-0.13	-0.06	-0.06	-0.06	-0.25	0.00	-0.56
Rods-Seepage Face							
1	-0.06	-0.13	-0.13	-0.06	-1.94	-0.25	-2.56
2	0.00	-0.38	0.00	-0.06	-0.25	0.00	-0.69
Rods-Basal Slope	----	----	----	----	----	----	----
Upper Rod-Debris	+0.25	-0.69	+0.06	0.00	+0.06	-1.31	-1.63
Slope							
Lower Rod-Debris	+0.13	-0.06	-0.63	0.00	-0.06	-0.31	-0.94
Slope							

## Site 4

Upper Rod-Tread	-0.06	-0.13	+0.25	-0.13	-0.06	+0.44	+0.31
Lower Rod-Tread	0.00	-0.06	-0.06	-0.06	-0.06	-0.06	+0.31
Rods-Seepage Face							
1	-0.06	-0.06	-0.25	0.00	-0.19	0.00	-1.13
Rods-Basal Slope							
1	+0.38	-0.88	-0.13	-0.06	-0.44	-0.31	-1.44
2	+0.63	-0.06	-0.75	-0.06	+0.13	0.00	-0.13
Upper Rod-Debris	+0.50	-0.38	+0.19	+0.06	-0.31	0.00	+0.06
Slope							
Lower Rod-Debris	+0.25	-0.06	0.00	-0.13	+0.56	-0.13	+0.50
Slope							

## Site 5

Upper Rod-Tread	+0.06	+0.06	0.00	0.00	-0.06	-0.06	0.00
Lower Rod-Tread	0.00	-0.06	-0.06	-0.06	0.00	0.00	-0.19
Rods-Seepage Face							
1	-0.13	+0.06	0.00	-0.06	0.00	0.00	-0.13
2	+0.19	-0.19	0.00	0.00	-0.19	0.00	-0.19
Rods-Basal Slope							
1	+1.75	-0.06	0.00	-0.19	-0.13	+0.06	+1.44
Upper Rod-Debris	+0.44	+0.69	+0.13	-0.13	+0.31	+0.13	+1.56
Slope							
Lower Rod-Debris	0.00	+0.13	0.00	0.00	+0.13	0.00	+0.25
Slope							

4/68	6/68	8/68	11/68	4/69	6/69	4/68
to	to	to	to	to	to	to
6/68	8/68	11/68	4/69	6/69	7/69	7/69

## Site 6

Upper Rod-Tread	+0.88	-0.94	-0.06	-0.44	+0.19	-0.06	-0.44
Lower Rod-Tread	+0.19	-0.56	-0.13	-0.38	-0.06	-0.31	-1.25
Rods-Seepage Face							
1	0.00	-0.06	+0.06	-0.06	0.00	0.00	-0.06
Rods-Basal Slope							
1	+0.19	+0.13	-0.13	-0.06	0.00	0.00	+0.13
2	+0.19	+0.38	0.00	-0.13	-0.31	-0.19	-0.06
Upper Rod-Debris	0.00	+0.19	+0.13	-0.06	+0.25	-0.06	+0.44
Slope							

## Site 7

Upper Rod-Tread	+0.13	-0.06	0.00	-0.06	-0.06	-0.13	-0.19
Lower Rod-Tread	0.00	+0.19	-0.19	0.00	+0.13	-0.19	-0.06
Rods-Seepage Face							
1	-0.13	+0.06	-0.06	0.00	+0.06	-0.06	-0.13
2	+0.06	-0.06	0.00	-0.06	0.00	-0.06	-0.13
Rods-Basal Slope							
1	+0.50	-0.75	-0.19	-0.13	+0.06	0.00	-0.50
Upper Rod-Debris	+0.31	-0.19	-0.44	0.00	-0.06	-0.06	-0.44
Slope							
Lower Rod-Debris	0.00	0.00	-0.06	+0.13	0.00	0.00	+0.06
Slope							

## Site 8

Upper Rod-Tread	+0.06	-0.19	-0.06	-0.25	+0.19	0.00	-0.25
Lower Rod-Tread	-0.19	-0.31	0.00	-0.25	0.00	-0.06	-0.81
Rods-Seepage Face							
1	0.00	-0.06	-0.13	0.00	-0.06	0.00	-0.25
2	0.00	-1.19	-0.13	+0.13	-0.56	+0.06	-1.69
Rods-Basal Slope							
1	+1.00	-0.13	0.00	-0.19	0.00	-0.06	+0.63
Upper Rod-Debris	+0.13	-0.06	-0.06	+0.25	+1.38	+1.00	+2.63
Slope							
Lower Rod-Debris	0.00	+0.25	0.00	0.00	0.00	0.00	+0.25
Slope							

4/68	6/68	8/68	11/68	4/69	6/69	4/68
to	to	to	to	to	to	to
6/68	8/68	11/68	4/69	6/69	7/69	7/69

## Site 9

Upper Rod-Tread	0.00	+0.13	-0.13	-0.13	+0.25	0.00	+0.13
Lower Rod-Tread							
1	0.00	0.00	-0.06	-0.13	+0.06	0.00	-0.13
2	0.00	-0.50	+0.44	0.00	-0.69	0.00	-0.75
Rods-Seepage Face							
1	0.00	0.00	+0.06	-0.06	0.00	0.00	0.00
Rods-Basal Slope	----	----	----	----	----	----	----
Upper Rod-Debris Slope	-0.06	+0.06	0.00	-0.19	+0.31	0.00	+0.13
Lower Rod-Debris Slope	0.00	+0.06	-0.06	0.00	0.00	+0.06	+0.06

## Site 10

Upper Rod-Tread	0.00	+0.38	+0.06	-0.13	+0.06	0.00	+0.38
Lower Rod-Tread	0.00	-0.06	-0.06	-0.19	+0.06	0.00	-0.25
Rods-Seepage Face							
1	-0.13	-0.50	+0.13	-0.06	0.00	-0.13	-0.69
2	+0.06	-0.25	0.00	-0.06	0.00	0.00	-0.25
Rods-Basal Slope							
1	+0.13	+0.25	-0.13	0.00	0.00	+0.13	+0.38
Upper Rod-Debris Slope	+0.06	+0.44	+0.13	+0.06	+0.44	-0.13	+1.00

## Site 11

Upper Rod-Tread	-0.06	0.00	-0.13	0.00	+0.19	+0.06	+0.06
Lower Rod-Tread	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rods-Seepage Face							
1	+0.50	-0.69	+0.13	0.00	-0.06	0.00	-0.13
2	+0.88	0.00	-0.06	-0.13	+0.06	0.00	+0.75
Rods-Basal Slope	----	----	----	----	----	----	----
Upper Rod-Debris Slope	+1.75	-1.44	0.00	+0.06	+0.06	+0.13	+0.56
Lower Rod-Debris Slope	0.00	+0.13	-0.06	-0.06	+0.06	+0.13	+0.19



4/68	6/68	8/68	11/68	4/69	6/69	4/68
to	to	to	to	to	to	to
6/68	8.68	11/68	4/69	6/69	7/69	7/69

## Site 12

Upper Rod-Tread	-0.06	0.00	-0.06	-0.25	+0.13	0.00	-0.25
Lower Rod-Tread	0.00	-0.75	+0.13	-0.06	+0.13	0.00	-0.56
Rods-Seepage Face							
1	0.00	-0.25	-0.06	-0.25	+0.25	0.00	-0.31
2	0.00	-0.31	-0.25	+0.19	+0.06	-0.06	-0.38
Rods-Basal Slope							
1	+0.50	0.00	0.00	0.00	0.00	-0.25	+0.25
Upper Rod-Debris Slope	+0.25	0.00	+0.25	-0.06	+0.38	0.00	+0.81
Lower Rod-Debris Slope	0.00	+0.31	-0.06	0.00	0.00	+0.13	+0.38

## Site 13

Upper Rod-Tread	0.00	0.00	0.00	0.00	-0.06	0.00	-0.06
Lower Rod-Tread	0.00	-0.06	+0.13	-0.13	+0.13	0.00	+0.06
Rods-Seepage Face							
1	+0.88	-0.25	+0.13	0.00	+0.06	-0.06	+0.75
Rods-Basal Slope							
1	+0.50	-0.94	+0.88	-0.19	+0.38	+0.06	+0.68
2	+0.63	-0.81	-0.38	-0.13	-0.13	-0.38	-1.19
Upper Rod-Debris Slope	0.00	+0.19	+0.06	-0.06	+0.13	-0.06	+0.25
Lower Rod-Debris Slope	+0.06	-0.06	-0.06	+0.13	+0.06	0.00	+0.13

## Site 14

Upper Rod-Tread	-0.06	+0.31	+0.19	-0.06	+0.13	0.00	+0.50
Lower Rod-Tread	0.00	0.00	0.00	-0.06	0.00	-0.06	-0.13
Rods-Seepage Face							
1	0.00	-0.06	+0.06	-0.06	-0.06	0.00	-0.13
2	-0.13	-0.88	+0.56	0.00	-0.06	-0.19	-0.69
Rods-Basal Slope							
1	0.00	-0.19	0.00	-0.13	+0.13	0.00	-0.19
2	+0.75	-1.38	+0.06	-0.06	+0.38	+0.06	-0.19
Upper Rod-Debris Slope	+0.13	+0.19	+0.06	-0.06	+0.19	0.00	+0.50
Lower Rod-Debris Slope	0.00	+0.88	+0.19	-0.06	+0.06	0.00	+1.06

4/68	6/68	8/68	11/68	4/69	6/69	4/68
to	to	to	to	to	to	to
6/68	8/68	11/68	4/69	6/69	7/69	7/69

## Site 15

Upper Rod-Tread	+0.06	-0.13	+0.06	+0.19	+0.06	-0.06	+0.19
Lower Rod-Tread	+0.06	0.00	-0.06	0.00	0.00	0.00	0.00
Rods-Seepage Face							
1	-0.06	0.00	-0.19	-0.06	0.00	0.00	-0.31
Rods-Basal Slope							
1	+0.25	-0.25	-0.06	-0.38	+0.25	-0.31	-0.50
Upper Rod-Debris	0.00	+0.06	0.00	+0.06	+0.06	0.00	+0.19
Slope							
Lower Rod-Debris	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slope							

## Site 16

Upper Rod-Tread	+0.06	-0.38	+0.25	+0.13	0.00	0.00	+0.06
Lower Rod-Tread	0.00	0.00	-0.06	+0.06	0.00	0.00	0.00
Rods-Seepage Face							
1	0.00	0.00	-0.06	0.00	0.00	0.00	-0.06
Rods-Basal Slope							
1	+0.50	+0.13	0.00	0.00	-0.06	0.00	+0.56
Upper Rod-Debris	+0.06	-0.06	+0.13	+0.06	+0.06	-0.13	+0.13
Slope							
Lower Rod-Debris	0.00	0.00	+0.13	-0.13	0.00	0.00	0.00
Slope							

## Site 17

Upper Rod-Tread	0.00	+0.31	+0.06	-0.81	+1.13	-0.13	+0.56
Lower Rod-Tread	+0.13	-0.13	-0.06	-0.25	+0.19	0.00	-0.13
Rods-Seepage Face							
1	0.00	+0.06	-0.38	+0.25	0.00	0.00	-0.06
2	-0.06	-0.44	+0.06	-0.06	-0.06	0.00	-0.56
Rods-Basal Slope							
1	+0.75	0.00	-0.06	-0.06	+0.06	0.00	+0.69
Upper Rod-Debris	0.00	+0.38	+0.06	+0.06	+0.19	-0.19	+0.50
Slope							
Lower Rod-Debris	0.00	+0.38	-0.31	+0.06	+0.31	0.00	+0.44
Slope							

4/68	6/68	8/68	11/68	4/69	6/69	4/68
to	to	to	to	to	to	to
6/68	8/68	11/68	4/69	6/69	7/69	7/69

## Site 18

Upper Rod-Tread	-0.19	+0.38	-0.19	0.00	-0.13	0.00	-0.13
Lower Rod-Tread							
1	0.00	-0.75	+0.19	-0.25	+0.19	0.00	-0.63
2	+0.13	-0.25	-0.06	-0.25	-0.25	-0.06	-0.75
Rods-Seepage Face							
1	0.00	-0.13	0.00	-0.06	0.00	-0.06	-0.25
Rods-Basal Slope							
1	+0.88	0.00	0.00	0.00	+0.06	+0.25	+2.19
Upper Rod-Debris	0.00	-0.06	-0.06	-0.06	-0.06	0.00	-0.25
Slope							
Lower Rod-Debris	+0.13	+0.31	+0.19	0.00	+0.13	0.00	+0.75
Slope							

## Site 19

Upper Rod-Tread	0.00	+0.56	0.00	+0.06	+0.25	0.00	+0.88
Lower Rod-Tread	0.00	+0.13	-0.06	-0.13	0.00	0.00	-0.06
Rods-Seepage Face							
1	0.00	-0.38	-0.25	0.00	+0.19	-0.06	-0.50
2	0.00	+0.06	-0.06	0.00	-0.31	0.00	-0.31
Rods-Basal Slope							
1	0.00	-0.13	-0.06	-0.06	-0.06	+0.06	-0.25
2	+0.50	-0.50	+0.06	-0.06	+0.13	0.00	+0.13
Upper Rod-Debris	+0.25	+0.38	-0.19	-0.06	+0.19	+0.06	+0.63
Slope							
Lower Rod-Debris	0.00	+0.50	0.00	0.00	+0.13	+0.06	+0.69
Slope							

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